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THE FIG "CANKER," CAUSED BY *PHOMA CINERESCENS* SACC.

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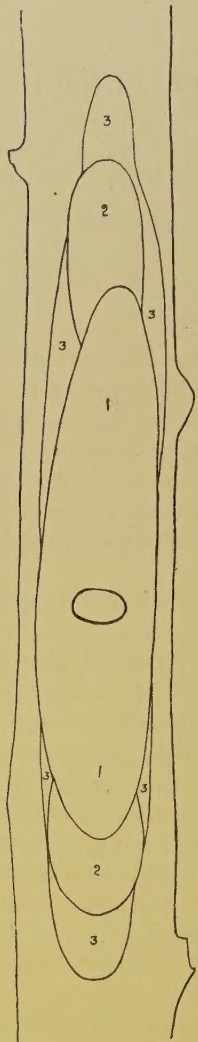
(With Plates I and II, and 1 Text-figure.)

IN 1914 complaints were received by the South-Eastern Agricultural College at Wye of serious diseases affecting the plantations of fig-trees in the district of Sompting, Sussex. On a visit being paid in May 1914 to the affected plantations, fig-trees of all ages were found to be suffering from fungous attacks of two kinds. A species of *Botrytis* was found on the tips of the branches, apparently gradually killing them back. This disease is still under observation and will be the subject of a further communication.

The second disease which occurred was a "canker" of the branches. In some cases, where old trees were badly attacked, numerous "cankers" were found, both on the younger branches, and on the old, main branches, often quite close to the ground. With the progress of the disease, the "canker" area enlarges, until the tissues extending through the branch are killed, with the result that the parts above die. With the successive removal of these "cankered" branches the productiveness of the tree is soon seriously impaired. The majority of the trees in these plantations are of the variety known as "Brown Turkey," but a few are of the "White Marseilles" variety. It was obvious from the effects produced that this "canker" disease was of serious economic importance; it was the opinion of the farmer of the largest fig-plantations that unless the cause of the disease could be discovered and a remedy devised the whole future of Fig-growing in that district was threatened.

The constant occurrence of a fungus with pycnidial fructifications on the cankered area was noted in the field, and the following notes were made from the examination of the material collected.

One of the "cankers" which may be taken as typical of those found on the larger branches is shown in the photograph at Fig. 1, Plate I, where the characteristic cracking of the bark in the older portions is seen. It will be observed that near the centre of the "canker" is the old base of a smaller branch and it is probable that that was the place where the fungus made an entrance. This particular canker was evidently the result of three distinct periods of activity of the causal organism. The oldest portion, recognized by the fact that the bark is very much cracked and separating from the wood, was elliptical and measured 16·5 × 5 cm. At each end of this ellipse the canker extended 5 cm. upward and 2·5 cm. downward, these extensions corresponding to the second period of activity. The check to the normal growth in thickness of the branch induced by the presence of the organism caused these affected areas to be depressed below the general surface of the branch. The youngest portions of the canker extended still further upward and downward and though they were but indistinctly marked off from the adjoining healthy portions of the branch they bore numerous pycnidia. The accompanying diagram of the canker shows the areas, affected during the three periods of activity, numbered respectively 1, 2 and 3; this diagram should be compared with Fig. 1, Plate I, which is a photograph of the same canker.



The portion of the branch bearing the "canker" was placed in a damp chamber and in twenty-four hours "tendrils" of conidia were issuing from the youngest portions of the canker but not from the rest. No conidia were obtainable from the older portions and there the fungus was either dead or had ceased to produce conidia, although these areas were still dotted over with old pycnidial pustules. The tendrils were at first of a pale orange colour but when fully protruded were almost or quite white. When a tendril or a portion of one is placed in a drop

of water the mucilaginous matrix binding the conidia together is dissolved and the conidia themselves stream apart and become diffused through the water; a slight "Brownian movement" is to be detected when the conidia are mounted in water.

Transverse sections through the bark show the fungal fructifications to be pycnidia. These bodies are more or less circular in outline and are from 250 μ to 600 μ in diameter; they are somewhat flattened and are therefore lenticular, appearing elliptical in transverse section. The pycnidia are produced a little below the surface, but on approaching maturity each develops a short neck which ruptures the outer layers of the bark and the tendril emerges through an apical pore. The wall of the pycnidium is lined with the conidiophores which are from 15 μ to 25 μ in length and which abstrict the conidia from their apices.

The conidia are continuous, ellipsoidal to fusiform, often with one extremity more rounded and broader than the other. Their dimensions are $6{\cdot}5$–$13 \times 2{\cdot}4$–$3{\cdot}6\,\mu$. Usually they are about $9 \times 3\,\mu$ and as a rule an increase of length is associated with a decrease in the width; thus the following dimensions are typical: $6{\cdot}5 \times 3{\cdot}6$, $9{\cdot}2 \times 3$, $11{\cdot}5 \times 2{\cdot}5$, $13 \times 2{\cdot}4$. With medium magnification they appear to be biguttulate, but by employing an oil-immersion objective this appearance is seen to be due to *two groups* of minute guttules. The two groups may merge into one another but usually they are quite distinct and situated at opposite ends of the conidium (see Fig. 10, Plate II).

The conidia are capable of germinating in water. When placed in a hanging-drop of distilled water and examined after remaining three days at the temperature of the laboratory (about 18° C.) a few of the conidia had germinated. They showed no appreciable increase in size before the protrusion of the germ tubes. The latter were at this stage one to four times the length of a conidium and frequently were more or less geniculate; they emerged laterally, sometimes at or near the middle of the conidium, at others more towards one or the other extremity, but none was seen truly polar.

In June of the same year (1914) Mr F. J. Chittenden sent us a specimen of the Fig "canker" from the glass-houses at Wisley; this bore pycnidia and conidia similar to those described above.

The pycnidial form of fructification and the spore-characters referred the fungus to the genus *Phoma*, and reference to Saccardo's *Sylloge Fungorum* enabled us to identify it with *P. cinerescens* Sacc. in *Mich.* I, p. 521 (1879). The specific diagnosis given is as follows: "Peritheciis gregariis, globoso-depressis, atrolivaceis, subcutaneis; sporulis

fusoideis, biguttulatis, 6–8 × 2–2·5, hyalinis. *Hab.* in ramis corticatis v. demum decorticatis *Fici Caricae,* in Italia et Gallia. Spermogonium *Diaporthes cinerescentis* Sacc."

To make certain of its specific identification, an example was sent to Prof. P. A. Saccardo, who replied, "J'ai examiné votre specimen. C'est sans doute mon *Phomopsis cinerescens.* Ma diagnose est incomplète, car les *sporophora* (comme il se fait très-souvent) étaient déjà disparus; aussi les *guttulae* dans votre specimen sont peu distinctes, mais cela est aussi variable." The author who transferred the present fungus from *Phoma* to *Phomopsis* was J. B. Traverso (in his *Flora Italica cryptogama,* vol. II, fasc. I, p. 278 (1906)), who after giving a description of *Diaporthe cinerescens* Sacc. merely remarks: "Status pycnidicus verisimiliter *Phomopsis cinerescens* (Sacc.) Trav. sporulis fusoideis, hyalinis, biguttulatis, 8 × 2." In general appearance and structure the present fungus agrees so well with other parasitic species which are still named *Phoma* that we retain it in that genus.

In searching for records of the occurrence of a Fig-tree "canker" in England, we met with the description given by Mr Massee first in the *Gardeners' Magazine,* for July 23 (1898), and later in his *Text-Book of Plant Diseases,* p. 431 (1903). In the former place Mr Massee wrote: "A disease presumably of old standing has of late years proved very injurious to fig-trees, and one remarkable feature in connection with this disease is the fact that it is most prevalent and destructive in those cases where the trees have received the greatest amount of attention, pruning more especially favouring its extension. The most usual symptoms of its presence are a cankered or ulcerated appearance of the bark, which frequently becomes eaten away in large patches, or variously cracked. In the majority of cases it is very evident that the canker first starts at a point where a branch has been cut away or accidentally broken off, and in all instances it appears that a broken surface of the bark is absolutely necessary to enable the fungus causing the disease to gain a foothold." While the general description of the disease given here agrees exactly with what we have found, the description of the fungus which Mr Massee gives as the causal organism is quite different from that of *Phoma cinerescens.* Mr Massee places his fungus in the *Melanconiaceae* ("perithecia absent; conidia produced on a more or less developed cushion or stroma formed beneath the surface of the matrix, and becoming erumpent") as a new species of the genus *Libertella,* viz. *L. ulcerata* Mass. In the *Gardeners' Magazine, l.c.,* it is stated: "Finally the fruit of the fungus, which is formed in

minute pustules, below the epidermis, bursts through to the surface, the exceedingly minute spores, only about 1–3,000 of an inch in length, oozing out through minute cracks in the epidermis, under the form of very slender, white, gelatinous threads or tendrils." The figure given of these spores is reproduced at Fig. 11, Plate II. It will be seen from Fig. 11, traced from Mr Massee's figure of the Fig canker *Libertella* in the *Gardeners' Magazine*, that the length of the conidia is about 1–3,000 of an inch (*i.e.* 8–9 μ), or approximately that of the conidia of *Phoma cinerescens* (compare Figs. 10 and 11, allowing for the difference in magnification). In *A Text-Book of Plant Diseases*[1] Mr Massee in describing his species under the name *Libertella ulcerata* Massee (sp. nov.) says, "Conidia fusiform, ends acute, continuous, curved, hyaline, 55–60 $\times$ 4 μ," and this description is repeated in his *Diseases of Cultivated Plants and Trees*[2]. This discrepancy in the accounts of the dimension of the conidia of *Libertella ulcerata* we are unable to account for. Our fungus, *i.e. Phoma cinerescens*, belongs to the *Sphaeropsidiaceae* ("perithecia containing conidia borne at the tips of slender conidiophores") and its conidia are ellipsoidal to fusiform, straight or slightly curved, ends usually rounded, averaging 9 $\times$ 3 μ, and never exceeding 13 μ in length.

The Herbarium at Kew was found not to contain the type specimen of *L. ulcerata* Mass. In March 1915, Mr Massee kindly forwarded to us an example of his fungus, writing "Enclosed is a fragment of the *type* specimen," and adding as a postscript, "I am almost certain that the *Libertella* is followed by a *Phoma* stage, but have not been able to get one from the other in cultures." The portion of the type specimen sent consisted of some hundreds of fructifications, mostly with dried-up tendrils of conidia still attached, and proved to be entirely *Phoma cinerescens*, with all the characters as described above. A thorough search of this type material showed no conidia resembling those described by Mr Massee, or any fructification of the type found in *Libertella*.

With reference to the parasitic nature of his fungus, Mr Massee states: "Experiments conducted on healthy young fig-trees show that the spores of the fungus—a species of *Libertella*—will not cause the disease when placed on the unbroken surface of even very young branches, whereas when the spores are placed on the end of a cut branch or on injured bark, inoculation always followed, and the mycelium was found in abundance at the expiration of 10 days. In one experiment

[1] Massee, G., *A Text-Book of Plant Diseases*, p. 431 (1903).

[2] *Idem*, *Diseases of Cultivated Plants and Trees*, p. 448 (1910).

a badly diseased branch, showing numerous threads of spores, was cut through; immediately afterwards the same knife was used for making an incision in the bark of a branch of a healthy young plant of *Ficus religiosa*. At the expiration of 10 days the wound showed undoubted symptoms of disease and at the end of five weeks the white threads of spores were found. This experiment proves that the disease may be imparted to healthy plants by using a knife that had previously been used for pruning diseased plants, and an examination of various diseased plants suggests the idea that this method of spreading the disease is not an unusual one."

Since the above work was not conducted with a pure culture of the fungus, and especially since we had found associated with the Fig "canker" disease a quite distinct fungus from that described by Mr Massee, it was important to obtain scientific evidence of the parasitism of *Phoma cinerescens*.

It was found that pure cultures could be obtained by two methods:

(1) A portion of a tendril obtained from the canker shown in the illustration (Plate I, fig. 1) was placed in a drop of sterilized distilled water; after dilution a small drop containing conidia was transferred to a tube of melted agar (prepared with an extract of prunes as nutrient) and a "poured plate" made. One such plate produced six sporelings; growth was rather slow and after eleven days the mycelial masses only measured from 4 to 7 mm. in diameter. From each of two of these a tube culture on an agar slant was prepared. In the tube cultures growth continued with more vigour and in seven days each showed a rather dense, flat, hyaline disc of mycelium about 2 cm. in diameter with a raised white ring of aerial hyphae midway between the point of origin and the periphery. Later these slant cultures consisted of a rich growth of dark brown mycelium with a few whitish tufts.

(2) An alternative method of obtaining cultures of the fungus was also adopted. The canker referred to above was cut across and transverse sections made through the discoloured wood. In this wood the vessels were found to be blocked with hyphae, tyloses and "wound-gum." Two small fragments of such sections made with a sterile razor were each transferred by means of a flamed platinum wire to an agar slant. The resulting growth resembled that obtained under similar conditions with mycelium produced from the poured plate of conidia, the white ring of aerial mycelium at a short distance from the point of inoculation again being a characteristic feature. The inference is that the mycelium in the affected tissues of the xylem is that of the

fungus seen on the exterior and indicates that it is possible to obtain a pure culture directly by transferring fragments of infected wood to a culture medium.

The medium used in these primary cultures was a decoction of prunes containing $1\frac{1}{2}$ per cent. agar and although it was found to be quite suitable for vegetative growth, no reproductive bodies were produced under those conditions. Sub-cultures made on sterilized cylinders of potato in Roux's tubes and on slabs of wood (obtained by making transverse slices[1] of a branch from a fig-tree) placed in Petri dishes and autoclaved at 115° C. for 30 minutes, readily produced pycnidia and "tendrils" of conidia. On potato the pycnidia were numerous and in some cases well-developed "tendrils" emerged, while in others the conidia accumulated at the mouth of the pycnidium in a globular mass, the latter condition obtaining when the moisture within the tube was too great for the typical tendrils to retain their characteristic form. The "tendrils" and globules of conidia were at first of an orange colour changing later to a dark red. The conidia were similar to those obtained originally directly from the canker in their size, shape and guttulation.

On the slices of fig wood the fungus grew vigorously as a white mycelium and eventually produced a few scattered "tendrils": the latter were larger (stouter and usually longer) than those normally produced under natural conditions and were dark red in colour, the conidia however were similar to those obtained from the canker itself. It is interesting to note in this connexion that the "tendrils" were more numerous on the under surface of the wood, *i.e.* where it came in contact with the inner surface of the Petri dish, than on the upper free surface.

INOCULATION EXPERIMENTS ON FIG-TREES.

Young fig-trees in pots were obtained for inoculation with pure cultures of the *Phoma* and were kept in a greenhouse throughout the experiments.

Experiment I. In this preliminary experiment a plate culture of the fungus was started on June 8, 1914 as a sub-culture from one of the tube-cultures mentioned above as obtained from a "poured plate" of conidia. At the end of eight days (June 16) there was sufficient mycelium for use in the following inoculations:

[1] These slices were 4–5 cm. diam. and about 1 cm. thick.

(1) A V-shaped cut was made through the bark of a branch of one of the young fig-trees; the triangular tongue of bark was turned back and a little agar bearing mycelium was removed from the plate culture and inserted between the bark and the wood. The free portion of bark was then pressed back into its place and the wound was covered up with cotton wool and tinfoil to prevent possible infection from air-borne spores. This precaution was perhaps unnecessary for as shown in Exp. II exposed wounds remained uninfected.

(2) From another branch a small portion of the bark (about 1 cm. × 0·5 cm.) was entirely cut away and agar with mycelium placed on the exposed tissues, after which the wound was bound up as in the previous case.

On September 16 the coverings were removed and the following results observed:

(1) Round the inoculated wound was a depressed very dark elliptical portion of bark 2·5 × 1·2 cm.; the tissue bordering the canker was pale in colour and thus showed strong contrast with the sunken canker. The latter bore a few pycnidia which appeared on the surface as small protuberances with incipient "tendrils" consisting of conidia which on microscopic examination were indistinguishable from those obtained from natural cankers.

(2) The result of the second inoculation was similar to the one just described except that the canker was smaller, its dimensions being 1·8 × 0·8 cm.; tendrils with typical conidia were again produced.

In both cases the infected branch was seen in September 1914 to be slightly swollen when viewed in a direction perpendicular to the surface of the canker. No further increase in the size of these cankers was subsequently observed and in the following season both branches bore fruit and leaves. In February of the present year (1916) leaves and fruit again appeared but by the middle of March the secondary branch immediately above the canker of the second inoculation, and on the same side of the main branch as the canker itself, showed signs of wilting for the leaves began to droop and turn yellow, indicating that the transpiration current was interrupted in the neighbourhood of the canker.

Experiment II. Semicylinders of potato were placed in Roux's tubes and sterilized in an autoclave by steaming at a temperature of 115° C. for 30 minutes; they were inoculated from an agar slant culture on June 22, 1914. The fungus grew vigorously on the potato; pycnidia were readily produced and by July 15 "tendrils" of conidia began to

appear. Later the latter were further developed and on September 29 were used for a second series of inoculations on fig-trees. Two of the "tendrils" were removed on a sterile hooked platinum wire and placed in a small tube of sterile distilled water which was then agitated in order to diffuse the conidia throughout the liquid. Wounds are made on branches as in Exp. I, but instead of inserting agar and mycelium, a drop of the water containing the conidia was transferred to the wound by means of a pipette (previously sterilized) and allowed to flow in between the bark and the wood. In the case of control wounds a drop of sterile water only was inserted in a similar manner. Some of the wounds were bound round with damp cotton wool (previously sterilized in autoclave) and tinfoil secured by raffia in order to ensure favourable conditions for the germination of the conidia: the other wounds were left uncovered. In other cases again water containing conidia and fragments of tendrils was dropped on damp cotton wool which was then bound round certain internodes with tinfoil and raffia as before, but without injuring the bark.

Eight of the largest branches on two young fig-trees, var. White Marseilles, were selected and treated as follows, the branches being from 0·8 cm. to 2 cm. in thickness.

No. 1. Inoculated; wound covered with cotton wool and tinfoil.
,, 2. As in 1.
,, 3. Inoculated; wound left uncovered.
,, 4. Control; not inoculated but branch cut and wound covered with cotton wool and tinfoil.
,, 5. Control as in 4.
,, 6. Control; wound left uncovered.
,, 7. Spores placed on damp cotton wool which was then wrapped round an internode.
,, 8. As in 7.

Eight branches were similarly selected on two young trees of the Brown Turkey variety and respectively treated as those of the White Marseilles. Thus in this experiment six branches were wounded and inoculated, with an equal number of control branches also wounded, and in four cases conidia were applied to uninjured branches.

To test the viability of the conidia used in the experiment a drop of the conidia-containing water (as used in the inoculations) was used in preparing a "poured plate" which was then placed in the greenhouse in close proximity to the trees. No growth was to be observed in the

plate for several days but on October 9 (*i.e.* when ten days old) numerous small mycelial masses were conspicuous.

Positive results were obtained in each case where the conidia had been inserted in the wound. The rest all yielded negative results.

The trees were examined from time to time and the progress of the disease in the inoculated branches noted as follows.

White Marseilles.

No. 1. (Branch about 1 cm. diam.)

Jan. 15, 1915. No change to be observed.

Feb. 16. No visible canker: no discoloration of the bark but "tendrils" were seen in the neighbourhood of the wound: they were arranged in the form of an irregular ellipse 2·2 cm. × 1·4 cm., elongated in a direction parallel with the axis of the branch.

Jan. 25, 1916. Distinct sunken canker 4 cm. long and extending laterally three-quarters round the branch.

No. 2. (Branch about 2 cm. diam.)

Jan. 15, 1915. No change to be observed.

Feb. 16. " " "

March 25. A single tendril of typical conidia was seen at 2 mm. above the wound; otherwise there was no change externally.

April 20. The bark round the wound was slightly depressed below the general surface; the affected area measured 1·5 × 1·5 cm.

Jan. 25, 1916. Distinct sunken canker 1·5 cm. long and extending one-third round the branch.

No. 3. (Branch 1 cm. diam.)

Jan. 15, 1915. No distinct canker (*i.e.* no sinking or cracking of the bark) but round the wound and extending 1 cm. above and below and 0·5 cm. laterally were numerous small protuberances; one of these pustules removed and mounted in water proved to be a pycnidium containing conidia as described above.

Feb. 16. Tendrils were issuing from the pustules which now covered an area 3·5 × 1·8 cm.

Jan. 25, 1916. Distinct sunken canker 5 cm. long and extending three-quarters round the branch.

Brown Turkey.

No. 1. (Branch 1 cm. diam.)

Jan. 15, 1915. No change to be observed.

Feb. 16. " " "

Mar. 3. A rather indistinct zone of discoloured bark (darker than the rest) was observed at 3–5 cm. from the wound.

Mar. 25. A single tendril of typical conidia was found at 2 mm. from the point of inoculation.

Jan. 25, 1916. Distinct sunken canker 2 cm. long and one-third round the branch.

No. 2. (Branch 0·8 cm. diam.)

Jan. 15, 1915. No change to be observed.

Feb. 16. The bark was discoloured for 2–3 mm. round the wound; at 4 mm. from the point of inoculation was a small group of pustules.

Mar. 3. A tendril was observed projecting from one of the pustules; it was removed and microscopic examination showed conidia as before.

Jan. 25, 1916. The affected area, now 2 cm. long and extending three-quarters round the branch, was only slightly depressed below the general surface but was distinguished from the rest by its darker colour.

Feb. 24. Branch dead above the canker, as shown by absence of any growth, the rest bearing leaves and young fruit.

No. 3. (Branch 1 cm. diam.)

Jan. 15, 1915. No external change.

Feb. 16. No canker and no discoloration noticeable but round the wound was an irregular circle (about 1 cm. diam.) of tendrils.

Jan. 25, 1916. The affected area appeared as a slightly sunken canker 2 cm. long and extending half-way round the branch.

Thus in the two series of experiments eight inoculations through wounds were made in all, and in every case not only was there a "canker" formed round the point of inoculation but the fruiting fungus appeared in the affected tissues and produced tendrils of conidia resembling those found on "cankers" arising from natural infections. Since "cankers" were so readily induced when the fungus, either in the form of conidia or of mycelium, was introduced into the internal tissues through wounds, the negative results in those cases in which conidia were applied to the uninjured bark indicate that in all probability the fungus is solely a wound-parasite.

Preventive Measures.

From our knowledge of the biology of the parasite, it is very unlikely that spraying with any fungicides will hold the disease in check. The direct measures should consist of a search for all "cankers," and the cutting of them out, down to the sound tissues, at a time when the disease is dormant; it will be advisable to paint over the wounds made with Stockholm tar. All dead branches must be cut out and *promptly burned*, as otherwise the fungus producing conidia on the dead wood might constitute a dangerous source of infection. The indirect measures

which should be employed—and these will be no less important than the direct measures—must consist of the prevention as far as possible of wounds to the bark. The making of wounds by the boots of men climbing in the branches when gathering the figs must be rigorously prevented, as well as those caused by careless hoeing or digging round the trees or due to the attacks of animals. The minimum amount of pruning to the older branches should be employed until the disease has been stamped out or reduced to a small amount.

DESCRIPTION OF PLATES I, II

PLATE I

1. Canker on a large branch of a fig-tree. $\frac{2}{5}$ natural size.

2. Lower half of the same canker, natural size, showing the small wart-like protuberances produced by the pycnidia.

3. Section through the bark of a canker; the pycnidial form of the fructifications is evident. $\times 60$.

PLATE II

4. Portion of a canker with "tendrils." $\times 4$.

5. Transverse section, natural size, through the middle of the canker shown in Fig. 1; the affected tissues were dark brown in colour.

6. *Phoma cinerescens* in pure culture on sterilized potato, natural size.

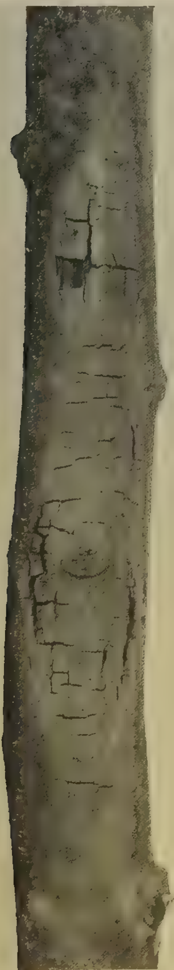
7. Two "tendrils" of *Phoma cinerescens* produced in pure culture on a slice of sterilized fig wood. $\times 4$.

8. Branch of fig-tree after inoculation with conidia taken from a pure culture, natural size; an irregular ring of "tendrils" at some distance from the wound is shown.

9. Another branch after inoculation with conidia; the protuberances produced by the pycnidia are seen around the wound.

10. A camera-lucida drawing of conidia of *Phoma cinerescens*; each conidium is provided with two groups of guttules. $\times 1000$.

11. Drawing traced from Mr Massee's illustrations, in the *Gardeners' Magazine*, of the conidia of the Fig canker *Libertella*. $\times 500$.



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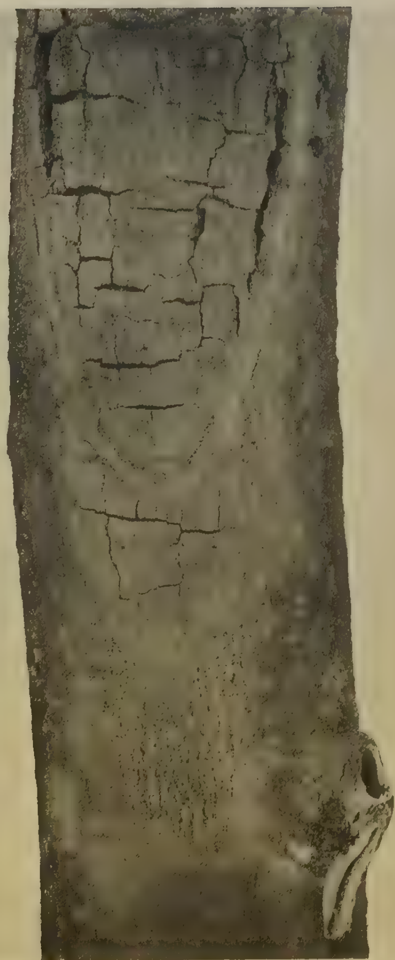

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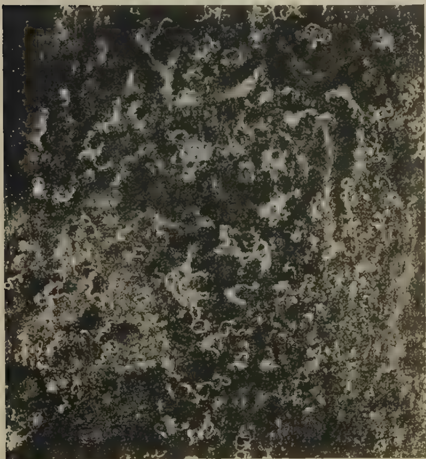

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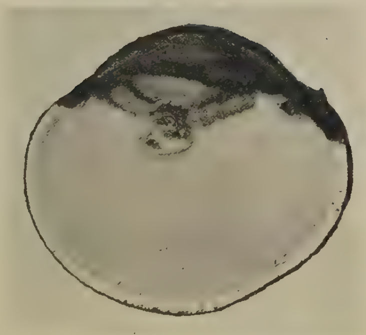

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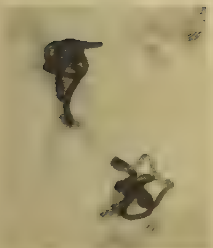

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SHRINKAGE, SWELLING AND WARPING OF CROSS-GRAINED WOODS: No. 1, YANG (*DIPTEROCARPUS* SP.).

By PERCY GROOM,

Professor of the Technology of Woods and Fibres, Imperial College, London.

(With a Diagram.)

No detailed investigations appear to have been conducted on the changes of dimensions and shape occurring during the wetting and drying of cross-grained woods. Yet such research bears upon problems that are of scientific as well as industrial importance; for many timbers growing in hot countries are cross-grained, that is to say, their fibres and other constituents in successive concentric layers round the longitudinal axis are directed alternately in right-handed and left-handed spirals. Moreover, a number of such timbers are of commercial importance.

The statistics available show that when straight-grained woods dry from their fresh (green) condition to an air-dried (ordinary seasoned) state the percentage shrinkages of their rods are as follows when cut: longitudinally, usually ·1 (·01–·8); radially, usually 3–5 (1·1–6); tangentially, usually 6–10 (1·8–10·5).

At first thought it might be anticipated that a cross-grained timber would show increased longitudinal but decreased transverse shrinkage or swelling, because of the existence of transverse and longitudinal components respectively. The results obtained do not bear out such an anticipation.

In this investigation the Indo-Malayan cross-grained commercial timber known as Yang, *Dipterocarpus* sp. (possibly *D. tuberculatus*), was used. When first imported into England it was tested as a substitute for teak (in window-cills, doors, etc.), and was sometimes

sold as "yang teak," but the results were not satisfactory. In-doors the wood twisted as it dried; while out-of-doors when it absorbed moisture yang was described as speedily showing on its surface a "white growth" and as undergoing early decay. During the progress of this investigation the practical problems of preventing these defects were more or less solved, and a digression on the cause of the disfigurement and decay out-of-doors may not be out of place.

Submersion of yang boards under water causes quantities of white substance to appear at intervals over the surface and especially at the ends. This substance is mainly resin that is forced out by the swelling of the woody tissue. I examined a few minute quantities of the substance dissolved in methylated spirit, and in each there occurred a microscopic fungal mycelium. When the sodden yang wood was allowed to dry the white substance remained as a disfiguring chalk-like exudation. When, in turn, a very little methylated spirit was rubbed over the surface of such dry wood, the disfigurement vanished as the resin dissolved and covered the surface with a film of varnish (recalling French polish in its effect). Practical trial alone can show the extent to which this treatment will preserve this wood from decay, or be of service in connexion with other resinous dipterocarp woods.

In the investigations the pieces of yang wood used were in the form of radially and tangentially cut boards, about 48–61 cm. in length, 12–13 cm. in width, and 1·35 cm. in thickness. In order to induce and measure the swelling they were submerged under water and measured at intervals. Thereafter they were allowed to dry at ordinary temperatures in the laboratory, and measured at intervals. The first measurements were made by means of a wooden rod graduated only to millimetres, but subsequently use was made exclusively of vernier callipers accurate to ·02 mm. The changes of curvature were recorded graphically by an instrument which Professor Dalby was so kind as to design for the purpose. The instrument is described in a separate paper, in the present issue.

General Results.

The most interesting results concerned the changes in length of the wood during the absorption and emission of water. In both cases a shortening and a lengthening took place. During the absorption of water the radial and tangential boards showed successively:

First, an increase of length together with relatively small increase of width. This latter, in the one case tested, was most marked near

the ends of the board, because the water was entering mainly through these.

Second, the boards actually shortened while at the same time they continued to widen.

Third, once more lengthening took place and was accompanied by widening.

During drying the reverse phenomena wholly or in part were exhibited; for the shortening at the beginning was succeeded by elongation, which was final in one case (yang 2) but was followed by lengthening in the case of yang 1; in all these cases the board continued throughout to shrink in width (excepting for occasional slight deviations).

Yet throughout these contrary changes in length the board continued to increase in surface during the absorption of water, and to decrease in surface during drying. And, in connexion with the explanation of the phenomenon, it is worthy of note that the board (tangential, yang 2) which showed the smallest ultimate decrease in length and most persistent elongation during drying yet experienced the greatest decrease in surface.

The most probable explanation of the reversal in change of length during the absorption of water appears to be one akin to that offered by Professor Brereton Baker, who suggested the analogy of a net-work or lattice-work in which swelling takes place more rapidly along the length than at right angles to this. In this case the meshes formed by the crossing vessels, fibres, and so forth are lozenge-shaped, narrow, and elongated along the axis of the tree-trunk (and board).

If we imagine two fibres or tracheae ABC and DBE intersecting at B, and consider the two sides BC and BE of the triangle CBE, then as water is absorbed by the board it is taken in most rapidly at the ends and travels more rapidly (in the vessels) along ABC and DBE than in any other direction. The result is relatively considerable elongation of BC and BE, with relatively inconsiderable increase in the angle CBE. Increased distribution of the water at right angles to BC and BE next causes more rapid expansion in those directions, tending to cause the two sides to rotate outwards about the centre B and thus cause a widening of the base of the triangle but a shortening of the perpendicular from B to that base. This would also take place if the sides elongated to a disproportionately small extent. Thereafter elongation of the two sides associated with disproportionately less expansion at right angles would cause a reversal of the immediately

preceding phase. Through these three phases the board named yang 2 passed, but during the final stage of elongation there were fluctuations, which possibly were due to the successive transverse belts or zones of the board at different distances from the ends being at different phases, and to irregularities in the rate of distribution of moisture in the board. Dotted lines in Diagram 1 illustrate, on a very exaggerated scale, the paths traversed by the points *C* and *E* during the absorption of water.

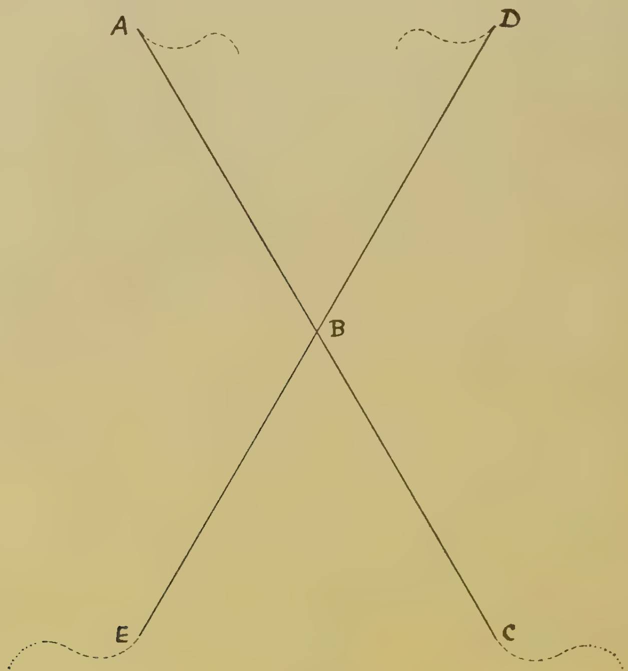

Diagram 1

When the board is drying and shrinking the reverse changes tend to take place, as drying is most rapid at the ends and presumably so along the lines of vessels. Yang 1 (tangential) went through such changes completely, but yang 2 (tangential) and the radial board showed merely the initial decrease and the succeeding increase in length; both associated with decrease in width. Dotted lines in Diagram 1 represent on a very exaggerated scale the paths of the points *D* and *A* during drying.

There is no absolute certainty that during soaking the boards had attained their maximum dimensions, though it is probable that such was at least approximately the case. The tangential board, yang 1, had certainly attained its greatest length; and judging by the lengths of the diagonals and widths so likewise had yang 2. When, as a result of drying, the boards had shrunk to their minimal recorded dimensions, these may be assumed to represent the true minimum sizes in relation to the surrounding atmosphere (dry air of the laboratory).

The changes in length were small or exceedingly small ultimately, being only ·012–·075 % of the maximum length. The changes in width at the ends were: tangentially, 5·92–6·29 % during drying, and 6·98 % (in the one case measured) during soaking; radially, during drying 5 % of the maximum width.

The subjoined Table gives the percentage changes of the (maximum) linear dimensions.

	Tangential Boards			Radial Board	
	Yang 1		Yang 2		
	Water absorbed 313 grammes	Water exhaled 307 grammes	Water exhaled 209 grammes	Water absorbed 316 grammes	Water exhaled 331 grammes
In length:					
maximum	—	·075	·030	—	·037
ultimate	·079	·063	·012	—	·020
In width:					
at ends	6·980	5·920	6·29	(5·5)	5·0
middle	7·400	5·980	—	—	—

The shrinkage in both length and width was less in all cases than the previous swelling, and this was so even when (in the radial board) more water was lost than had originally been absorbed. This permanent expansion of pieces of wood after soaking in water appears not to have been recorded, and it remains to be seen whether or no straight-grained woods show the same behaviour. That some change takes place in wood by the prolonged action of water at high temperatures (steam) is well known, and reveals itself in permanent decrease of elasticity and strength.

Although during drying and soaking respectively lengthening and shortening may take place, the area of the faces of the board always decreases and increases respectively during those processes. So much does the change in width correct any reverse change in length that the board yang 2 when drying lost in area to a greater extent than did the other boards despite of the fact that its ultimate decrease in length was much the smallest.

One marked character of at least some cross-grained woods is their liability to twist during wetting and drying, and the tangential boards of yang displayed this character. The two tangential boards of yang showed on their faces the grain running obliquely apparently in the same sense in each board, but in opposite senses in the two boards. Thus on each face of yang 1 the grain tended to run from the right hand to the left hand down the board, whereas in yang 2 it tended to run from left to right downwards. Considering either of these boards on one face the one diagonal running rather with than across the grain changes relatively slightly in length as the board becomes wetter or drier, whereas the other diagonal on the same face changes more in length becoming concave when drying or convex when wetting: the diagonals superposed on these on the reverse face behave in an opposite manner. The result is that each face of the board becomes convex along one diagonal, and concave along the other; that is to say a twisting movement results from the establishment of a couple. That this explanation is correct is confirmed by the fact that the twist is in the opposite sense during the swelling and drying of the same board; and is in the opposite sense in the two boards yang 1 and yang 2 when these are undergoing the same kind of change of water contents, whether this change be drying or wetting.

Moreover if such be the true explanation of the twisting a radially cut board should not exhibit this behaviour. The radially cut yang board showed no trace of twisting either when wetted or dried. These facts suggest, on the one hand, that possibly the twisting of so-called straight-grained boards in general is due to a less marked and differential obliquity on the two faces, and on the other hand that cross-grained woods now excluded from commercial use by reason of their twisting propensities could be utilized if they were cut into radial ("quartered," "rift-sawn") boards. The facts also emphasize the advisability of seasoning cross-grained woods not only thoroughly, but also slowly, the latter because the extent of the twist is largely influenced by the rate of drying of the surface.

In a transverse direction the tangential boards at their ends remained nearly straight, the very slight amount of curvature possibly conforming with the moderate degree of tangential shrinkage or swelling.

Observations on Yang 1.

This board was tangentially cut, its length and width slightly exceeding 61 cm. and 12·85 cm. respectively.

The two faces were labelled y and Y respectively, Y and Yx, y and yx denoting the four corners of what may be termed the top of the board, y and Y being at the same edge or corner: similarly Yb and Yxb, yb and yxb denoted the four corners at the bottom end of the board. Consequently the lengths of the board on the two faces are represented by measurements $y \, . \, yb$, $yx \, . \, yxb$, $Y \, . \, Yb$, $Yx \, . \, Yxb$, of which $y \, . \, yb$ and $Y \, . \, Yb$ represent the same margin of the board on two different faces, as do $yx \, . \, yxb$ and $Yx \, . \, Yxb$. The diagonals were thus $Y \, . \, Yxb$, $Yx \, . \, Yb$, $yx \, . \, yb$, and $y \, . \, yxb$.

In this cross-grained board on each face the grain runs from the top towards the bottom in a direction from right to left hand, though on face Y the grain is to a considerable extent nearly straight on the lower (bottom) half.

Observations. Set A (Table A).

The first measurements of yang 1 were made on a board, already partially seasoned in the timber-yard, during its drying in the laboratory. As a simple measuring rod was used the longitudinal changes in length were too small for accurate estimation, but the changes in length of the diagonals and in width were sufficiently considerable for approximate measurement and are recorded in the accompanying Table A.

In accordance with the direction of the grain the shrinkages along the two diagonals $Y \, . \, Yxb$ and $yx \, . \, yb$ were greater (·2 and ·15) than along the other two diagonals, so that the board became concave along the former pair and convex along the latter pair. The two ends of the board were thus twisted so as to lie in different planes, but they nevertheless retained their transverse straightness approximately.

TABLE A.

Date	Weight in grammes	Diagonals in centimetres				Width in centimetres	
		$Y \, . \, Yxb$	$Yx \, . \, Yb$	$y \, . \, yxb$	$yx \, . \, yb$	Top	Bottom
April 28	761·4	60·7	59·7	61·1	61·1	12·9	12·85
„ 30	751·2	—	59·65	61·05	61·05	12·8	12·7
May 3	—	60·6	59·6	61	61	12·7	12·6
„ 10	733·54	60·55	59·625	61·05	61	12·75	12·6
„ 19	738·85	—	—	—	—	12·75	12·6
June 1	725·35	60·5	59·6	61	60·95	12·7	12·525
Total difference	36·05	0·2	0·1	0·1	0·15	0·2	0·325

Set B (Tables B I and B II.)

The next set of measurements (B) were made on the board as it was compelled to swell by submersion under water: vernier callipers and Professor Dalby's instrument being used for the observations.

The main results as evidenced by the statistics given in Tables B I and B II, and as proved by the graphic records (unpublished) of the curves, are:

The absorption of water at first causes a sudden relatively considerable increase in length, which is relatively more marked than the increase of width even at the ends. This is succeeded by a decrease in length, which is synchronous with a more rapid gain in width.

The water enters most largely by the ends; the gain in width is marked here at first, and only after some time does the middle of the board display a similar full rate of widening.

As water continues to be absorbed the board, after undergoing its peculiar shortening, gradually lengthens and attains its maximum length even before it has absorbed the maximum amount of water, after which one or more times a shortening was noticeable. These contrary fluctuations as regards length are probably to be attributed to the fact that as the water penetrates from the ends the transverse belts at increasing distances from the two ends successively go through the shortening and lengthening phases, so that the measured result as regards the whole board is the algebraic sum of a number of items that are unequal and at times opposite in sense.

Widening of the board continued as long as water was absorbed, but the slightness of the increase in width towards the conclusion of the soaking strongly suggests that the maximum width had been very nearly reached.

Table B I records the changes in linear dimensions of yang 1 during the absorption of water. The results of these measurements are arranged in Table B II, by grouping together measurements made at short intervals on the same day, and by taking the averages of the longitudinal, transverse end, and transverse middle measurements.

In reference to these Tables it was conceivable that two sources of misinterpretation were possible. On the one hand curvature or straightening of the board might cause a spurious appearance of shortening or lengthening respectively. On the other hand the interval necessarily intervening between the weighing of the board and the recording of the measurements and curves would lead to a certain degree

TABLE B I. *Absorbing water.*

Date	Hour	Weight in grammes	Difference	Longitudinal $yx.yb$	Difference	$y.yb$	Difference	Tangential $y.yx$	Difference	$yb.yxb$	Difference	Middle	Difference	
VI. 21	12.30	721·650	—	61·026	—	61·032	—	12·710	—	12·540	—	12·478	—	After measurement left in the damp air of a hot-house until VI. 22. 10
,, 22	10	738·1	16·45	,, ·050*	·024	,, ·054*	·022	,, ·838	·128	,, ·662	·122	,, ·562	·084	After measurement placed in water for 2½ hours
,, ,,	2.15	797·25	59·15	,, ·072*	·022	,, ·076*	·022	13·452	·614	,, ·857	·195	,, ·592	·030	
,, 23	11.15	841·5	44·25	,, ·036	–·036	,, ·030	–·046	,, ·624	·172	13·320	·463	,, ·856	·264	
,, ,,	3.15	842·6	1·1	,, ·039	·003	,, ·034	·004	,, ·628	·004	,, ·345	·025	,, ·902	·046	Measurements begun at 3.15 and continued until 4.15, when weighing took place
,, 24	11.15	881·7	39·1	,, ·052	·013	,, ·058	·024	—	—	(,, ·414)	—	—	—	
,, ,,	12·10	874·3	–7·4	,, ·052	·0	,, ·069	·011	,, ·624	–·004	,, ·419	·074	13·160	·258	After 12.10 submerged, then (at approximately 2.35) measured, curves taken, and finally weighed at 3.30
,, ,,	3.30	873·6†	– ·7†	,, ·055	·003	,, ·060	–·009	,, ·626	·002	,, ·424	·005	,, ·180	·020	
,, 25	11.15	901·6	28·0	,, ·060	·005	,, ·072	·012	,, ·622	–·004	,, ·432	·008	,, ·324	·144	
,, ,,	12.30	891·5	–10·1	,, ·058	–·002	,, ·074	·002	,, ·620	–·002	,, ·426	–·006	,, ·330	·006	
,, 28	10.15		46·6	,, ·073	·015	,, ·102	·028	,, ·630	·010	,, ·472	·046	,, ·434	·104	Measurements, curves etc. begun at 10.15, weighed at 11.45, then renewed measurements begun at 12
,, ,,	12	938·1		,, ·072	–·001	,, ·086	–·016	,, ·628	–·002	,, ·470	–·002	,, ·434	·0	
,, 29	11.20	967·3	29·2	,, ·074	·002	,, ·082	–·004	,, ·630	·002	,, ·474	·004	,, ·440	·006	Measured then weighed, then curves taken, then measured again
,, ,,	12.20			,, ·072	–·002	,, ·082	·0	,, ·630	·0	,, ·472	–·002	,, ·440	·0	
VII. 1	10.15			,, ·076	·004	,, ·090	·008	,, ·634	·004	,, ·482	·010	,, ·446	·006	Measurements and curve-taking begun at 10.15, weighed at 11.57, then measurements re-made
,, ,,	12	986·6	19·3	,, ·073	–·003	,, ·088	–·002	,, ·632	–·002	,, ·480	–·002	,, ·445	–·001	
,, 5	11.55	1017·1	30·5	,, ·072	–·001	,, ·086	–·002	,, ·648	·016	,, ·494	·014	,, ·472	·027	
,, 7	11	1034·6	17·5	,, ·072	·0	,, ·085	–·001	,, ·645	–·003	,, ·502	·008	,, ·478	·006	
Total difference			312·95		·046		·053		·935		·962		1·000	
Percentage difference of the final dimensions			—		·075		·087		6·85		7·1		7·4	

* These numbers were originally recorded as 60·5, 60·522, 60·504, and 60·526 but I feel sure that I recorded in each case ·5 in place of ·05; hence the alterations of the original records.

† The comparative estimated numbers are 880·9 and +6·3.

TABLE B II.

Date	Hour	Weight in grams.		Length in cm.		Width of ends in cm.		Width of middle in cm.		Length × average width of the ends	Area = length × average width	Increase of area per 10 grammes of water absorbed, when estimated by length × average width of	
			gain		difference		difference		difference			ends	whole board
VI. 21	—	721·65	—	61·029	—	12·625	—	12·478	—	770·491	765·975	—	—
„ 22	10	738·1	16·45	„ ·052	·023	„ ·750	·125	„ ·562	·084	778·413	772·674	4·8	4·07
„ „	2.15	797·25	59·15	„ ·074	·022	13·154	·404	„ ·592	·030	803·367	786·206	4·2	2·3
„ 23	—	842·05	44·8	„ ·035	– ·039	„ ·479	·325	„ ·879	·287	822·691	804·380	4·3	4·06
„ 24	12.10 3.30	874	31·95	„ ·059	·024	„ ·523	·044	13·170	·291	825·701	814·893	0·94	3·29
„ 25	—	896·55	22·55	„ ·066	·007	„ ·525	·002	„ ·327	·157	825·918	819·872	0·096	2·2
„ 28	—	938·1	41·55	„ ·079	·013	„ ·550	·025	„ ·434	·107	827·620	824·078	0·41	1·01
„ 29	—	967·3	29·2	„ ·077	– ·002	„ ·551	·001	„ ·440	·006	827·654	824·234	0·012	0·05
VII. 1	—	986·6	19·3	„ ·082	·005	„ ·557	·006	„ ·445	·005	828·089	824·668	0·22	0·22
„ 5	—	1017·1	30·5	„ ·079	– ·003	„ ·571	·014	„ ·472	·027	828·903	825·849	0·266	0·387
„ 7	—	1034·6	17·5	„ ·078	– ·001	„ ·573	·002	„ ·478	·006	829·011	826·080	0·06	0·13
Total difference		—	313·	—	·049	—	·948	—	1·00	58·52			
Percentage of the final dimensions		—	—	—	·079	—	6·98	—	7·4	7			

The swelling per cent. in a tangential direction is 91 times that in a longitudinal direction.

of inaccuracy as to the exact amount of water present in the board at the time of the records. Both these objections are shown in the succeeding remarks to be groundless as regards the essential results obtained.

Rate of loss of water during measurement and recording of curves. The board was first left in very damp warm air for nearly 24 hours (VI. 21–22); on June 22nd during measurement and so forth from 10 a.m. to 11.45 a.m. it lost water at the rate of 1·7 grammes per hour. In this case the water was wholly hygroscopic and in the cell-walls. On other days in summer in the dry laboratory air the board lost water during measurement etc. in most cases at the rate of 7·2 grammes per hour (VI. 22 from 2.15 to 3.5 p.m., and from 3.5 to 3.30 p.m.; VI. 23 from 11.15 a.m. to 12.5 p.m.; VI. 25 from 11.15 a.m. to 12.30 p.m.), though on one day (VI. 24 from 11.15 a.m. to 12.15 p.m.) the rate was 8·1. In these cases it may be assumed that the loss of water was largely at least at the expense of that present in the lumina of the wood, and at the surface of the sides. These figures render possible an approximately accurate estimate of the amount of water present in the wood at the middle of the time occupied in recording measurements and curves on any day.

In regard to the estimates of the amount of water in the board and the length the following cases may be discussed. On June 24th observations were made in the following order: at 11.15 a.m. the board was weighed (881·7 g.), then curves and measurements were taken until 12.10 p.m., when the board was once more weighed (874·3) and a second set of curves and measurements were immediately taken. When these last were concluded the approximate weight would be 874·3 − 7·3 = 867 g. The board was then submerged until 2.30 p.m., when curves and measurements were made before it was weighed (873·69) at 3.30, so that at 2.30 p.m. its approximate weight was 880·9. But whether these corrected or the recorded weights be accepted the changes in linear dimensions are not proportional to the change in the amount of water contained. During this phase these dimensions are determined rather by the exact distribution than by absolute amount of the moisture, probably because the water is largely passing from the lumina into the cell-walls whether the wood be soaking or drying.

Again on June 28th, 29th, and July 1st, to begin with the measurements and curves were taken, then the board was weighed, after which a second set of measurements and curves were made. This second set therefore represents the wood in a drier condition (11, 7·3, and 12·5 grammes of water respectively having been lost) so that the linear

dimensions are smaller than in the first set. Accordingly the average between the two sets of measurements represents more accurately the linear dimensions at the recorded weight.

The subjoined Table B III reports the changes of curvature lengthwise of yang 1 (during the absorption and exhalation of water) along the two sides *y . yb* and *yx . yxb*.

TABLE B III.

y . yb					*yx . yxb*					
Date		End *y*	Middle	End *yb*	Date		End *yx*	Middle	End *yxb*	
VI. 21	2	*vs*	*c* (2)	*c*	VI. 21		(*vs*)	*c* (3)	*c*	Absorbing water
,, 22	11.40	*S* to *cs*	*c* (3)	*c*	,, 22	11.30	*S* to *cs*	*c* (3)	*c*	
,, ,,	2.25	*c*	*c* (5)	*c*	,, ,,	2.30	(curve defectively taken)			
,, 23	11.15	*cs*	*c* (4)	*c*	,, 23	11.30 (circa)	(*vs*)	—	*cs*	
,, ,,	4.10	*cs*	*c* (4·25)	*c*	,, ,,	4.15	*v*	*vs*	*vs* to (*cs*)	
,, 24	11.46	*Sn*	*Sn*	*Sn*	,, 24	11.30	*S*	*S*	*S*	
,, ,,	3.10	*Sn*	*Sn*	*Sn*	,, ,,	3.35	*S*	*S*	*S*	
,, 25	11.15	*Sn*	*Sn*	*Sn*	,, 25	11.45	*S*	*S*	*S*	
,, 28	11 to 12	(*vs*) to (*cs*)	*cs* (·75)	—	,, 28	11.45	*S*	*S*	*S*	
,, 29	11.55	*S*	*S*	*S*	,, 29	11.50	*S*	*S*	*S*	
VII. 1	11.10	*v* (·9)	*S*	*S*						
,, 5	11.40	*v* (·75)	*S*	*S*	VII. 5	11.35	*S*	*S*	*S*	
,, 7	11.17	*v* (2·25)	(*v* 2)	*v*	,, 7	11.25	*S*	*S*	*S*	
,, 9	12.53	(A wavy concave to straight line)			,, 9	12.45	*S* (*vs*)	*S*	*S*	Drying
,, 13	12.6	*c*	*c* (1·5)	*c*	,, 13	12.10	*c*	*c* (3·25)	*c*	
,, 15	11.57	*c*	*c* (1·5)	*c*	,, 15	11.50	*c*	*c* (3·25)	*c*	
,, 16	11.17	*c*	*c* (1·5)	*c*	,, 16	11.30	*c*	*c* (3·25)	*c*	

The first four columns refer to *y . yb*, the others to *yx . yxb*. Columns 1 and 5 give the dates and times of observation. The other columns denote the curvature: and as the curve of each side is often not uniform along its whole length, each column headed "middle" refers to the curvature at the middle of the length, while the remaining columns headed "end" give the curvatures at the end of each of the two halves of the length. In the columns: *c*, *cs*, and (*cs*) respectively mean "concave," slightly so, or very slightly so; *v*, *vs*, (*vs*) respectively mean "convex," slightly so, or very slightly so; *S* and *Sn* mean straight and nearly straight respectively; the number succeeding in brackets in columns gives the number of millimetres of the middle above or below the straight or base line.

The statistics given in Table B III when compared with those of Table B I show in particular that the unexpected shortenings of the

board during the absorption of water are true, and not due to increased curvature. This is true of the changes in length between June 22nd and 23rd, and July 1st to 9th.

Changes in transverse curvature. In like manner Table B IV shows on comparison with Table B I that the measurements recorded of the widths are not determined by the transverse curvatures; even when there is a considerable difference in the amount of widening of the two ends (June 25th to 28th) this is not associated with any corresponding difference of curvature.

TABLE B IV.

Date and times		*yb . yxb* Change of shape	Change of width	*yx . y* Change of shape	Change of width	
VI. 21		Concave		Concave		Absorbing Water
,, 22	10.30 10.45	Less concave (tends to straighten)	·122	Less concave (tends to straighten)	·128	
,, ,,	3 2.50	More concave (curves)	·195	*Vigorously* convex in middle (curves equally)	·614	
,, 23	11.50 12	More concave throughout (curves)	·463	Less convex (tends to straighten)	·172	
,, 24	3.5 3	Concave throughout	·104	Still less convex (tends to straighten)	·002	
,, 25	12.30 12.20	Nearly straight (straightens)	·005	Minutely convex (tends to straighten)	–·005	
,, 28	10 10.5	,, ,,	·043	,, ,,	·009	
,, 29	11.35 11.40	,, ,,	·002	Straight	·0	
VII. 1	11.45 11.57	,, ,,	·007	Minutely convex	·003	
,, 5	11.45 11.50	,, ,, (June 25 to July 5: as a whole minutely *concave*, nearly straight)	·015	Nearly straight (June 25 to July 5: as a whole minutely *convex*, nearly straight)	·013	
,, 7	11.12 11.7	Practically straight	–·008	Practically straight	–·003	
,, 13	12.40 12.45	Slightly convex (curves)	·586	Became concave (curves more)	·631	Drying
,, 15	12.12 12.10	Minutely concave (curves)	·034	Slightly more concave (curves more)	·024	
,, 16	11.10 11.16	Definitely concave ,,	·058	Concave, about = VII. 13; hence it straightens slightly	·034	

Set C (Tables C I and C II).

The subjoined Table C I records the linear changes of dimensions of the same board (yang 1) during the process of drying from an approximately saturated condition to a state of aqueous equilibrium with the air of the laboratory. Table C II gives the averages of the results obtained.

In addition to details that will be discussed subsequently in comparing swelling and shrinkage, two facts are worthy of note.

1. During shrinkage there is reached a certain phase at which the board elongates while still decreasing in width. This phase, when judged by the amount of water contained, is not exactly synchronous with the corresponding reverse one during swelling. As in the latter case this reversal in the change of length is temporary and is succeeded by longitudinal shrinkage that brings the board down to its earlier shortened condition.

2. Whereas the board when absorbing water at first widens more rapidly at the ends than in the middle, when drying it contracts in width more rapidly at the middle than at the ends. Two possible explanations of this latter fact present themselves. (*a*) When drying owing to the more rapid conduction along than across the grain there is near the ends a rapid shortening which tends to cause the angle of inclination of the crossing fibres to be increased with consequent tendency towards widening; while in the middle of the board the loss of water takes place more equally and more or less excludes this widening tendency. (*b*) Or possibly at first during the drying the water near the ends is largely in the lumina, as well as in the walls, so that the latter do not lose much, while the evaporation draws water to the ends from the middle, which probably contains less water in the lumina and becomes depleted of this more rapidly than at the ends. Between these alternatives it is impossible to decide until further researches are conducted on shrinkage in general.

Changes of dimensions of Yang 1 during Swelling and Shrinkage.

During swelling the percentage average increases in linear dimensions were: in length ·079; in width at the ends and middle 6·98 and 7·4 respectively. Thus the percentage tangential elongation was 91 times as great as the longitudinal.

TABLE C I.

Date	Time	Weight in grammes	Difference	$yx.yxb$	Difference	$y.yb$	Difference	$y.yx$	Difference	$yb.yxb$	Difference	Middle	Difference	
VII. 7	11	1034·6	—	61·072	—	61·085	—	13·645	—	13·502	—	13·478	—	Measured, then weighed, the curves then taken, then weighed again (12 o'clock), then measured
,, ,,	12	1026·85	7·75	,, ·068	·004	,, ·076	·009	,, ·640	·005	,, ·496	·006	,, ·470	·008	
,, 8	10.40	885·1	141·75	,, ·066	·002	,, ·074	·002	,, ·582	·058	,, ·444	·052	,, ·412	·058	
,, 9	10.45	826·2	58·9	,, ·040	·026	,, ·050	·024	,, ·514	·068	,, ·378	·066	,, ·252	·160	
,, ,,	4.30	811	15·2	,, ·024	·016	,, ·042	·008	,, ·436	·078	,, ·324	·054	,, ·165	·087	
,, 12	4	752·1	58·9	,, ·028	– ·004	,, ·050	– ·008	,, ·058	·378	12·970	·354	12·861	·304	
,, 13	11	747·5	4·6	,, ·028	·0	,, ·052	– ·002	,, ·014	·044	,, ·916	·054	,, ·839	·022	
,, 15	10.35	746*	1	,, ·032	– ·004	,, ·058	– ·006	12·990	·024	,, ·882	·034	,, ·830	·009	
,, 16	10.50	741·625	4·375	,, ·028	·004	,, ·057	·001	,, ·956	·034	,, ·824	·058	,, ·790	·040	
,, 19	10.30	742·4	– ·775	,, ·032	– ·004	,, ·056	·001	,, ·963	– ·007	,, ·832	– ·008	,, ·807	– ·017	
XI. 29	—	726·82	15·58	,, ·032	·0	,, ·048	·008	,, ·828	·135	,, ·711	·121	,, ·672	·135	
(XII. 10)	—	(728)												
Total difference			307·28		·040		·037		·817		·791		·806	The mean between the two end contractions ·791 and ·817 is ·804, while middle contraction is ·806
Percentage of full swollen length					·065		·060		6 nearly		5·86 nearly		5·98	

* Fragment weighing ·59 fell off, hence to this and all subsequent weights ·59 must be added. July 14 much rain fell; July 15 the air was moist and weather threatening.

TABLE C II.

Date	Time	Weight in grammes		Mean length in cm.		Mean end width in cm.		Middle width in cm.		Length × width of ends	Decrease of area per 10 grammes of water lost, estimated by length × width, average of	
			Difference	*yyb . yxyxb*	Difference	*yyx . ybyxb*	Difference		Difference		ends	whole board
VII. 7	11	1034·6	—	61·0785	—	13·5735	—	13·478	—	829·011	—	—
,, ,,	12	1026·85	7·75	,, ·072	·0065	,, ·568	·0055	,, ·470	·008	828·625	0·5	0·66
,, 8	10.40	885·1	141·75	,, ·070	·002	,, ·513	·055	,, ·412	·058	825·239	0·24	0·24
,, 9	10.45	826·2	58·9	,, ·045	·025	,, ·446	·067	,, ·252	·160	820·811	0·75	1·23
,, ,,	4.30	811	15·2	,, ·033	·012	,, ·380	·066	,, ·165	·087	816·621	2·75	3·2
,, 12	4	752·1	58·9	,, ·039	– ·006	,, ·014	·366	12·861	·304	794·361	3·76	3·46
,, 13	11	747·5	4·6	,, ·040	– ·001	12·965	·049	,, ·839	·022	791·383	6·47	4·6
,, 15	10.35	746·5	1·0	,, ·045	– ·005	,, ·936	·029	,, ·830	·009	789·678	(16·95)	(10·95)
,, 16	10.50	742·125	4·375	,, ·0425	·0025	,, ·890	·046	,, ·790	·040	786·838	6·48	6·07
,, 19	10.30	742·9	– ·775	,, ·044	– ·0015	,, ·8975	– ·0075	,, ·807	– ·017	784·538	—	—
XI. 29	—	727·32	15·58	,, ·040	·004	,, ·7695	·128	,, ·672	·135	779·481	4·97	4·9
Total difference			307·28		·0385		·804		·806	49·53		
Percentage of initial maximum			·2		·063		5·92		5·98	6 (circa)		

The swelling per cent. in a tangential direction is 94 times as great as that in a longitudinal direction

During shrinkage the board did not dry completely to its original condition (it retained only about 5·5 g. more water), but making allowance for this fact, its shrinkage was not relatively (nor absolutely) so great as the swelling. The percentage average decreases in linear dimensions were: in length ·063; in width at the ends and middle 5·92 and 5·98 respectively. The percentage tangential shortening was 94 times as great as the longitudinal.

Changes in area. During absorption and emission of water it has been shown that synchronous longitudinal and tangential changes in dimensions may be opposite in sense. The question arises therefore: During absorption and emission of water does the volume or surface as a whole always respectively increase and decrease? The statistics available prove that a decrease and increase in the amount of water respectively cause corresponding decrease and increase in area: thus anomalous changes in length are overborne by the more normal changes in width (the one apparent exception recorded in Table C II July 19th is discussed later).

The subjoined Table D records the changes in surface for each ten grammes of water gained or lost. In order to show the corresponding conditions as regards the statistics concerning drying and soaking respectively the data are ranged in columns in reverse order.

TABLE D.

	Swelling		Shrinking		
Date and hour	Increase of area per 10 grammes of water	Weight of board and water	Decrease of area per 10 grammes of water	Weight of board and water	Date and hour
VI. 21	—				
,, 22 10	4·07	721–874	4·97	727–826	XI. 29
,, ,, 2.15	2·3		6·07		VII. 16
			(10·95)		,, 15
,, 23	4·06		4·6		,, 13
,, 24	3·29		3·46		,, 12
,, 25	2·2	874–896	3·2		,, 9 4.30
,, 28	1·01	896–938	1·23	826–885	,, 9 10.45
,, 29	0·05	—	—	—	—
VII. 1	0·22	967–986	0·24	885–1026	,, 8
,, 5	0·387	986–1017	0·66	1026–1034	,, 7 12
,, 7	0·13	1077–1034	—	—	—

Both sets of observations show that the greatest change in area (and, judging by the statistics concerning the radial board, in volume) induced

by gain or loss of the same amount of water takes place when the wood is poor in water, and that as the wood contains larger amounts of water there is a decline in such a change in area. This is in part due to the larger proportion of water present in the lumina of the wetter wood; moreover if we assume that the same loss of water always causes the same decrease in volume of the solid wood-substance (cell-wall) the smaller diameters of the wood-constituents in the dry phase have to be considered. But the irregularities in changes of area near the beginning and conclusion of the drying and soaking require explanation. One source of misinterpretation is brought out by the change between July 16 and 19, when there was a slight hygroscopic absorption of water and yet a decrease in area: probably this additional moisture was superficially distributed to a considerable extent, and the main mass of the wood was probably drier on the later date. During drying, small changes in weight of the board may on the one hand be associated with relatively greater changes in the distribution of moisture within the board; moreover during such small changes a slight underestimation of the amount of water lost will cause the increase in area to appear excessive. And it will be noted that during drying apparently unduly large results are associated with small changes of weight, viz. on July 7, 11 to 12 a.m., July 12–13, July 13–15, and July 15–16. On these dates the maximum result (dividend) appears when the loss of water recorded was the minimum (July 13–15). During soaking there were no such small changes in weight, and, excepting at the beginning and end, no sudden or great changes in the rate of dimensional increase. The contrast between the results between June 21 and 22 at 10 a.m., and June 22, 10 a.m. to 2.15 p.m., is possibly due to the fact that the increased water-content during the former period was due to slow absorption of aqueous vapour, and during the latter period to rapid intake of liquid water much of which would be in the lumina and in operation on swelling; but the unexplained smallness of the increase in width of the middle of the board on June 22 is also partly responsible.

Twisting of Yang 1.

The warping along the length and transversely across the ends have already been discussed; it remains to consider the warping along the diagonals and the consequent twisting.

The deviations from the straight were measured in millimetres on the curves recorded by Professor Dalby's instrument; but as the

latter doubles the deviation the number recorded in the subjoined Table E must be halved in order to give the true facts. The measurements recorded from June 21 to July 7 relate to the board during the absorption of water, those subsequent to July 17 to the drying board.

The diagonal *yx . yb* runs rather across the grain exposed at the surface and consequently underwent greater elongation and shortening than did *y . yxb*, which tends more towards parallelism with that grain. The lengths of the diagonals measured were approximately 56 centimetres.

In Table E:

Column 1 represents the time of observation.

Column 2 records the amount of water absorbed subsequent to the immediately preceding period.

Columns 3 and 7 record the nature of the curve, whether concave (*c*), or convex (*v*), or straight (*s*) of the whole board along the diagonal and the number of millimetres that the middle is sunk or raised above the true base line as recorded by the instrument.

Table E.

1	2	3	4	5	6	7	8	9	10
		yx . yb				*y . yxb*			
		Shape and deviation				Shape and deviation			
Date and hour (circa)	Grammes of water absorbed	Whole	*yx* half	*yb* half	Twist deviation	Whole	*y* half	*yxb* half	Twist deviation
vi. 21	—	*c* 16·25	11·25	12·0	54	*v* 8·75	7·75	6·75	4·75
,, 22 11	16·45	*c* 15·5	11·75	9·25	51	*v* 8·25	6·5	6·25	3·75
,, ,, 3.25	59·15	*c* 14·25	6·5	12·5	53	*v* 9·75	7	6·75	6·75
,, 23 11	44·8	*c* 9·25	3·75	8·5	33·5	*v* 4·5	3	3·5	8
,, 23 3.50	1·1	*c* 9·25	4·5	8·25	37	*v* 4·375	3	3	0
,, 24 12	32	*s* 0	0	0	1	*v* ·8	·5	0	0
,, ,, 2.50	−·7	*s* 0	0	0	0	*s* 0	0	0	0
,, 25 12.5	18	(*s*) 0	0	0	0	*s* 0	0	0	0
,, 28 11.20	46·6	(*v*) 0	(*v*) ·75	*s* 0	0	*s* 0	0	0	0
,, 29 12	29·2	*v* 1·5	1·5	·7	0	*s* 0	0	0	·5
vii. 1 11.35	19·3	*v* 1·5	·75	·5	·25	*s* 0	0	0	0
,, 5 11.25	30·5	*v* 2·5	2·0	1·0	·5	(*c*) ·5	·5	·1	1·0
,, 7 11.30	17·5	*c* 2·75	2·5	1·25	0	(*c*) ·5	·5	·1	1·75
,, 9 12.30	−208·4	*c* 2·75	2	2·5	0	(*c*) ·1	·375	·1	0
,, 13 12.30	−78·7	*c* 13·5	9	10·0	44				
,, 15 11.30	− 1·0	*c* 15	11·25	11·5	51				
,, 16 11.45	− 4·4	*c* 16	11·5	11·75	52				
xii. 10 12	−13·6	*c* 18·75	13·5	14·0	64				

Columns 4, 5, 8, 9 similarly record the deviation in millimetres of the middle point of each half of the respective diagonals; columns 4 and 8 denoting the half (top) towards the *y* . *yx* end, and columns 5 and 9 denoting the half (bottom) towards the *yb* . *yxb* end.

Columns 6 and 10 record the amount of twist by giving the number of millimetres that the end point is raised above the base line, as recorded by the instrument.

Table E shows that on June 21 the dry board was warped and twisted, being on one face (*y*) concave along one diagonal *yx* . *yb* and convex along the other, *y* . *yxb*. With the absorption of water these diagonals by differential elongation lost their curvature, and were almost or quite straight on June 24 and 25. As water continued to be absorbed until July 5 the original curvatures of the diagonals were gradually reversed, *yx* . *yb* becoming convex and *y* . *yxb* concave, the reversal taking place more obviously along *yx* . *yb* (crossing the grain). During the drying from July 7 onwards (and even before this, for some unknown reason, in the case of *yx* . *yb*) the curvatures gradually reverted to those originally present in the dry board.

It is worthy of note that the amounts of warp and twist were not exactly determined by the amount of water contained. This fact is demonstrated by comparisons between the conditions of the board on June 21 and on July 16 and December 10. The greater twist and warp during the final drying are probably due to the fact that the loss of water was more rapid in the warm dry air of the laboratory than during the original industrial seasoning of the board. This consideration emphasizes the special importance of carefully regulated seasoning of cross-grained woods.

Observations on Yang 2.

The board named yang 2 was cut tangentially and its faces were lettered as in the case of yang 1; on one face, *Y* and *Yx* denoting the top corners, *Yb* and *Yxb* the bottom corners; and on the other face, *y* and *yx*, *yb* and *yxb* denoting the corresponding points, but *y* was superposed on *Y*, that is to say *Y* and *y* are at the same edge of the board. Thus for instance *YYb* and *yyb* represent the same side of the board on the two different faces and *Y*. *Yxb* and *y*. *yxb* represent the same diagonal on the two faces.

Set F.

The first set of measurements, recorded in Table F, were made by means of the measuring rod during the absorption of water. The changes in length were too slight to be accurately estimated. On the other hand measurements of the diagonals and across the two ends were possible, and evidence in favour of their substantial accuracy is supplied by the fact that the widening of the board at both ends was the same on the average, viz. ·6375: moreover on the face y it was ·65 at each end, and on face Y ·625 at each end. This represents a widening of 5·3 per cent. of the full length attained. But it must be noted that when the board was first placed in water it was not sufficiently dry to be in equilibrium with the atmospheric humidity of the laboratory; this was proved in the second set of observations when the board was dried.

TABLE F.

		Diagonal				Transverse (tangential)			
Date	Weight	$Y.Yxb$	$Yx.Yb$	$y.yxb$	$yx.yb$	$Y.Yx$	$y.yx$	$Yb.Yxb$	$yb.yxb$
April 29	588·4	44·5	44·3	44·3	44·3	11·5	11·55	11·25	11·25
May 3	672·6	44·6	44·5	44·5	44·4	12·08	12·1	11·75	11·8
„ 5	688	44·6	44·5	44·475	44·4	12·05	12·125	11·8	11·85
„ 11	763·6	44·65	44·55	44·6	44·475	12·1	12·175	11·85	11·9
„ 17	787	44·6	44·5	44·55	44·475	12·125	12·2	11·875	11·9
Difference between Apr. 29 and May 17	—	0·1	0·2	0·25	0·175	0·625	0·65	0·625	0·65

During soaking the board twisted, but the direction of the twist was opposite to that of yang 1 in conformity with the fact that on the two faces its exposed oblique grain ran in directions representing spirals reverse in sense to those of yang 1. On face Y, the diagonal $Y.Yxb$ ran more with the grain and therefore showed less elongation (·1) than did $Yx.Yb$ (·2) which was directed more across the grain and became convex. For the same reason the elongation of $yx.yb$ (·175) was less than that of $y.yxb$ (·25). Consequently of the two superposed diagonals $Yx.Yb$ and $yx.yb$ the former became convex and the latter concave: while of the other two superposed diagonals $y.yxb$ became convex and $Y.Yxb$ concave: the result was the above mentioned twist. Naturally in subsequent drying these relations were reversed.

Set G.

The results of the measurements of yang 2 during its final process of drying from a saturated condition are given in Table G.

The board at first decreased in length, but thereafter continued to elongate. In this respect it differed from the tangential board yang 1, but agreed with the radial board. The final loss of length was exceedingly small, merely ·012 per cent. of the maximum length, but the maximal loss was ·03 per cent. These figures are far less than those for yang 1, and even less than for the radial board.

The shrinkage in width of the ends was 6·29 per cent. of the maximum width, and was thus greater than those of yang 1 (5·92) and the radial board (5).

When the shrinkage in area is assessed by the changes in length and in width of the ends it will be seen that the loss of width atoned for the slightness in the shortening: for the shrinkage of area was 41·266 cm.^{2}, compared with 49·53 cm.^{2} in the case of yang 1. Yang 2 was only about 48 cm. long, whereas yang 1 was about 61. Had yang 2 been of the latter length its contraction in area would have been (*circa*) 52·43 cm.^{2}, thus slightly more than that of yang 1.

The changes in length and width from May 28, 1915 to February 4, 1916, are worthy of special note as they occurred when the board was so far dry that it gained or lost water solely according as the air became moister or drier; and during this phase the weight of the board varied only between 570·075 and 570·48 g.

Radially Cut Board.

The first set of observations were made while this board was absorbing 309 g. of water. As a measuring rod was employed for the purpose the longitudinal measurements were found to be useless. As regards the transverse measurements the ultimate increase in width was 5·5 per cent. of the maximum attained. This statistic is not of value as showing the full radial expansion, for it was subsequently found that when first measured (and weighed) the board was not fully dry in relation to the laboratory air. Its original weight was 719 g., whereas at the conclusion of the second set of observations the board had dried down to a weight of 706·5 g.

During the soaking, in contrast with the tangential boards, the radial board remained flat and devoid of any twist.

TABLE G.

Date	Weight	Length in centimetres: $Y \cdot Yb$	$Yx \cdot Yxb$	$y \cdot yb$	$yx \cdot yxb$	Average	Width in centimetres: $Y \cdot Yx$	$y \cdot yx$	$Yb \cdot Yxb$	$yb \cdot yxb$	Average
May 17	779·5	48·036	47·982	48·03	47·982	48·0075	13·720	13·752	13·534	13·552	13·640
,, 18	761·3	,, ·035	,, ·982	,, ·03	,, ·982	,, ·00725	,, ·702	,, ·744	,, ·529	,, ·538	,, ·628
,, 19	659·8	,, ·020	,, ·970	,, ·014	,, ·964	47·992	,, ·672	,, ·719	,, ·482	,, ·492	,, ·591
,, 28	570·1	,, **·028**	,, ·964	,, **·016**	,, **·965**	,, **·993**	12·844	12·882	12·706	12·704	12·784
June 3	570·15	,, ·032	,, ·972	,, ·018	,, ·970	,, ·998	,, ·854	,, ·900	,, **·696**	,, **·702**	,, ·788
July 13	570·075	,, **·035**	,, **·974**	,, **·021**	,, **·972**	**48·0005**	,, ·854	,, ·900	,, ·686	,, ·696	,, ·784
Feb. 4	570·48	,, **·032**	,, ·975	,, ·024	,, ·974	,, ·00125	,, **·848**	,, ·900	,, ·688	,, **·692**	,, **·782**
Difference May 17–Feb. 4	—	·004	·007	·006	·008	·006	·872	·852	·846	·860	·858
Difference maximum	—	·016	·018	·016	·018	·015	·876	·870	·848	·860	

Percentage difference (decrease) of the maximum length: April 17 to Feb. 4, ·012; April 17 to 28, ·03.
,, ,, ,, ,, width, 6·29.
Absolute ,, ,, area, 41·266 sq. centimetres.

Set H.

In the second set of measurements, made on the radial board while this was drying, vernier callipers were employed, and the results are recorded in Table H.

During this thorough and at times rapid drying the board, in sharp contrast with the tangential boards, remained flat and untwisted.

During drying the shortening was slight, only ·025 or ·04 per cent. of the maximum length, being intermediate in this respect between the two tangential boards. Reverse changes in length took place, as during two phases elongation took place while at the same time decrease in width was marked. Especially worthy of note is the fact that elongation continued to the final period of drying (June 18 to November 29). Such synchronous elongation and narrowing took place not only during the period June 14 to 16, when the board was drying, but actually continued between June 16 and 17 during a slight absorption of atmospheric moisture. This latter fact was probably caused by the smallness of the amount of the water absorbed and its incomplete distribution through the wood.

The decrease in width of the ends was 5 per cent. of the maximum width, and thus less than in the tangential boards (5·92 and 6·28).

During the process of drying, even when the board was elongating, the area of the faces (as assessed by length, and width of the two ends) continued to decrease. The whole decrease in area was less (40·907) than in the tangential boards.

There is evidence that soaking caused the board to increase in width permanently, for the succeeding statistics show that for similar changes in water-contents shrinkage in width during drying was less than expansion in width during soaking. It must be noted in regard to these statistics, that during soaking the width measured was not the whole width of the board but the distance between two pencil points 11·325 to 12·15 cm. apart, whereas during drying the whole width of the board, 13·258 to 12·802 cm., was measured. Hence for perfectly similar comparison the statistics of widening given below are too small.

	Change of weight	Gain or loss of water	Change of width of $Y . Yx$ and $Yb . Yxb$
Board absorbing water	722·1—1038 g.	315·9 g.	·6 cm.
„ losing „	1038—723·3 g.	−314·7 g.	−·5 cm.
„ absorbing „	719·1—1038 g.	318·9 g.	·655 cm.
„ losing „	1038—717·4 g.	−320·6 g.	−·577 cm.

Table H.

Date	Weight in grammes: Weight of board	Weight in grammes: Loss of water	Length in centimetres: $Y.Yb$	Length in centimetres: $Yx.Yxb$	Length in centimetres: $y.yb$	Length in centimetres: $y.yxb$	Width of ends in centimetres: $Y.Yx$	Width of ends in centimetres: $y.yx$	Width of ends in centimetres: $Yb.Yxb$	Width of ends in centimetres: $yb.yxb$	Average length in centimetres: Length	Average length in centimetres: Difference	Average width of ends in centimetres: Width	Average width of ends in centimetres: Difference	Average area in square centimetres (length × average end width): Area	Average area in square centimetres (length × average end width): Difference	Decrease of area per 10 c.c. of water lost
VI. 9	1038		61·052	61·042	(61·062)	61·032	13·258	13·238	13·316	(13·330)	61·047		13·285		811·009		
,, 10	891·1	146·9	,, ·050	,, ·038	,, ·060	,, ·028	,, ·230	,, ·212	,, ·288	,, ·306	,, ·044	·003	,, ·259	·026	809·382	1·627	0·11
,, 11	818	73·1	,, ·040	,, ·030	,, ·047	,, ·019	,, ·172	,, ·152	,, ·232	,, ·236	,, ·034	·010	,, ·198	·061	805·527	3·855	0·53
,, 14	732·75	85·25	,, ·016	,, ·024	,, ·032	,, ·018	12·900	12·877	12·878	12·876	,, ·0225	·012	12·883	·315	786·146	19·381	2·27
,, 15	723·3	9·45	,, **·030**	,, ·010	,, **·038**	,, **·020**	,, ·770	,, ·752	,, ·802	,, ·810	,, **·0245**	– ·002	,, ·783	·100	780·070	6·076	6·43
,, 16	717·4	5·9	,, ·028	,, **·026**	,, ·037	,, ·016	,, ·710	,, ·695	,, ·750	,, ·764	,, **·0267**	– ·002	,, ·730	·053	776·873	3·197	5·42
,, 17	717·7	– ·3	,, ·030	,, **·024**	,, ·038	,, ·017	,, **·704**	,, **·688**	,, **·748**	,, **·764**	,, ·0272	·0005	,, **·726**	– ·004	776·620	0·253	8·43
,, 18	713·8	3·9	,, ·024	,, ·024	,, ·036	,, ·010	,, ·670	,, ·650	,, ·723	,, ·728	,, ·0235	·004	,, ·693	·033	774·565	2·055	5·27
XI. 29	706·52	7·28	,, **·032**	,, **·033**	,, **·043**	,, **·020**	,, ·589	,, ·576	,, ·638	,, ·668	,, **·032**	– ·009	,, ·618	·075	770·102	4·463	6·38
Difference:																	
VI. 9–XI. 29 (whole)	—	—	·020	·009	·019	·012	·699	·662	·678	·662	—	·015	—	·667	—	40·907	—
VI. 9–VI. 14	—	—	—	—	—	—	—	—	—	—	—	·0245	—	—	—	—	—

Percentage loss of the maximum length: final (June to November), 0·025.
" " " " maximum (June 9th to 14th), 0·04.
" " " width: final and maximum, 5.
Finally percentage loss of width = 200 × percentage loss of length.

Figures printed in thick type mark cases where the change in dimensions is in sense contrary to the change in the amount of contained water a minus sign denotes the same.

While 323 (715·2 to 1038) g. of water were absorbed the average *measured* width of the same face decreased by ·612 cm., whereas while the board underwent more thorough drying and lost 331·5 (1038 to 706·52) g. of water, the average *whole* width decreased by ·673 cm., which represents a decrease of ·606 on the width measured during absorption.

I have pleasure in tendering thanks to Professor Dalby for his extreme kindness in inventing and providing the instrument for registering the changes in curvature, and to Mr Alexander Howard for presenting the boards for investigation.

THE DALBY PROFILE RECORDER.

By W. E. DALBY, M. Inst. C.E., F.R.S.

Professor of Engineering, City and Guilds Engineering College.

(With 7 Text-figures.)

1. Introduction.

A short time ago Professor Groom asked me if a method could be devised to enable him to measure the shape of the surface of a timber sample with reasonable speed and accuracy so that measurements taken from time to time could be compared in order to study questions relating to the warping of timber.

In response to this request I designed a machine by means of which the shape of the surface could be explored and recorded automatically without the necessity of taking a single measurement directly.

The result of the exploration of the surface by the machine is a drawing showing the shape of the surface along parallel lines spaced at definite distances apart.

Such a drawing is seen in Fig. 1. It is the result of exploring an artificially prepared surface of a piece of pine along five parallel lines. The surface was made specially irregular in order to illustrate the working of the machine.

The five datum lines numbered respectively 1 to 5 and the corresponding profile curves were drawn in 3 minutes. The datum lines are spaced 1 inch apart and the length of the record is about 2 feet. The size of the sample used in the particular machine in which the record was drawn is $30\frac{1}{2}$ inches long and 6 inches wide.

The curves on the drawing are really the profiles of five equidistant sections of the timber sample taken normally to a reference plane. The profiles recorded show the variations of shape to twice the actual size for convenience of measurement. The machine can be designed to give the record the actual size or any multiple of it.

2. The Reference Plane.

The machine is so designed that the datum lines in the record correspond to lines lying in a common plane in the timber sample.

This plane is called the Plane of reference. The plane of reference in the timber sample corresponding to the lines on the record is defined by any selected point on the timber surface to be explored. Having selected a suitable point the exploring roller of the apparatus is set to the point and then the plane through this point parallel to the plane defined by the surfaces of three studs to which the sample is clamped is the plane of reference from which ordinates to the surface are to be measured. The roller was set on the sample to the point corresponding to Z in Fig. 1.

A reference to Fig. 2 will make this clear. A, B, C are three supporting studs in the machine. The upper surfaces of these studs define a plane. Let a piece of timber be laid on these three points. Let Z be the point in the upper surface of this piece of timber to which the exploring roller is set. Then a plane through Z parallel to the plane defined by the points A, B, C is the Plane of reference from which all ordinates are measured to the undulating surface. In all forms of the machine there will be found three supporting studs corresponding to the points A, B, C. These studs may be regarded as three blunted points, the upper surfaces of which define what may be called the Plane of the machine.

The plane of reference is parallel to the plane of the machine at a distance from it determined by the particular point in the surface to which the roller is set at the beginning of the process of taking a record.

The traces of these planes are shown in the vertical elevation Fig. 3.

If the point Z is in the same plane as the points A, B, C then the plane of the machine and the plane of reference coincide. This condition is practically fulfilled in some

Fig. 1. Profile curves from an artificially prepared surface of a piece of pine.
In the original record the datum lines are 1 inch apart.

forms of the machine. In other forms the three points A, B, C are in the lower surface of the timber sample and the point Z is in the upper surface so that the plane of reference is above the plane of the machine by approximately the thickness of the sample.

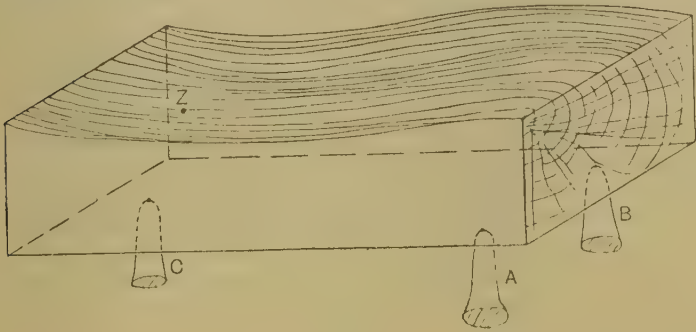

Fig. 2

It is only when the sample is clamped at three points that a true record of the surface can be made. The act of clamping at more than three points distorts the timber so that the family of profile curves correspond to a surface slightly strained, and the surface will therefore change in shape immediately the sample is removed from the machine. When however it is clamped at three points only the

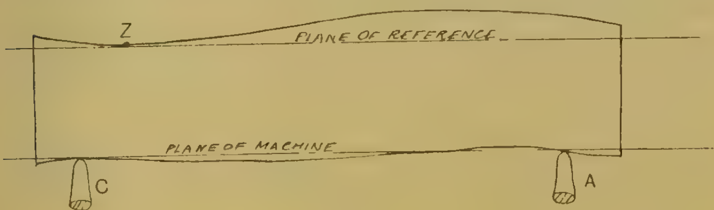

Fig. 3

sample is quite unstrained, and moreover it can be removed from the machine and can be replaced in it again in the same position relatively to the frame, providing always that it is clamped at the same three points. The initial clamping points should therefore be carefully marked on the sample by ringing them round or by any other convenient method.

The position of the point Z must also be carefully marked on the surface so that the exploring roller can be re-set to this point when taking subsequent records of the surface. The re-setting to Z ensures that the families of profile curves in all the series of records which may be taken of the surface are recorded in relation to the same reference plane. In other words by re-setting the roller to Z the position of the reference plane in relation to the plane of the machine is maintained substantially without change however often the sample is replaced in the machine. In the time elapsing between two successive measurements of a family of profile curves of the surface, warping slightly changes the distances of the point Z on the surface from the clamping points; but the change is quite negligible in its influence on the position of the reference plane if the point Z is initially chosen close to a clamping point. In Fig. 1 for example, Z is taken as close to the clamp A, Fig. 4, as possible. It would probably be better in a definite series of experiments to take Z as near to the central clamping point as possible (C in Fig. 4). Then the warping of the surface would have the least effect in changing the relative positions of the reference plane through Z and the plane of the machine.

Warping and shrinking also change the relative positions of the three clamping points themselves during lapse of time. The change is likely to be slight and the effect on the relative position of the reference plane and the plane of the machine negligible. To secure uniformity in practice it is advisable to re-clamp a particular sample so that the central clamp (like C Fig. 4) grips the timber at the same point in all the re-settings of the series. The clamps A and B will then grip the sample at points displaced from the original points by amounts due to shrinkage in the linear dimension of the imaginary triangle formed by joining the three points at which the sample was originally clamped.

In cases where great accuracy is required the hole-slot-plane method of clamping may be used. Assuming the timber to be hard enough to bear clamping without appreciably indenting the surface, a conical hole is formed in the timber to receive the conical point C (Fig. 2); a V-groove pointing towards C is formed to receive the conical point B; and the surface of the timber rests on the conical point A. The timber sample when clamped down on to these conical points is then fixed relatively to the frame of the machine in the most accurate manner possible.

In cases where the timber is soft and therefore the conical supporting points are likely to form indentations in the surface, metal

screws may be screwed into the timber, the heads of these screws being specially formed, the screw at C with a conical hole, the screw at B with a V-slot, and the screw at A with a plane head.

The reference plane will stand at a fixed distance from the plane of the machine defined by the hole-slot-and-plane clamping except for the negligibly small error produced by warping and shrinking in the distances of Z from the clamping points. This error is minimised by selecting Z as close to the conical hole as possible.

3. General Description of a Recorder.

The particular form which the profile recorder takes depends upon the purpose for which it is required and upon the sizes of the samples which are to be tested.

Apparatus may be designed for drawing the profile curves of the largest planks or for studying samples of moderate size or for measuring the shape of the blades of an aircraft propeller.

One type (Mark 2) is shown by the photographs Figs. 4 and 5. This apparatus takes samples $30\frac{1}{2}''$ by $6''$ and any thickness up to $1\frac{1}{2}''$. Variations in the shape of the surface are shown twice the actual size in the record. This multiplication of the surface variations can be carried to any extent desired but the scale once settled remains constant for any particular machine.

Referring to Fig. 4 the timber sample T is clamped down by the clamps A, B and C to the corresponding studs below it. The drawing paper on which the records are to be taken is pinned down to the drawing board at D. The angle iron framework is self-contained and supports on the one side the timber sample and on the other side the drawing board.

Lying on the bottom bars of the framework is a guide frame GG consisting of two parallel rods secured in end pieces. It will be seen that this frame can be lifted from its position and can then be placed in another position defined by any one of four pairs of V-notches cut in the lower bars of the framework. These notches are pitched 1 inch apart.

The stock of the machine is supported by the guide frame. It is shown separately in Fig. 5. Its base is made of cast iron and it is grooved to slide along the guide bars GG seen in Fig. 4. It is pushed along them by hand when a profile curve is being drawn.

The stock carries an exploring roller R on the end of an arm and a

pencil *P* on the end of another arm. Mechanism connects the two arms so that the vertical movement of *R* is changed into a horizontal movement of the pencil in a direction at right angles to the direction of motion of the stock.

To draw a profile curve the stock is placed on the guide frame *GG* and the mechanism is locked in a zero position by turning the milled head *L* seen at the lower part of Fig. 5. The roller is clamped clear of the surface. The pencil is then lowered on to the paper and the stock

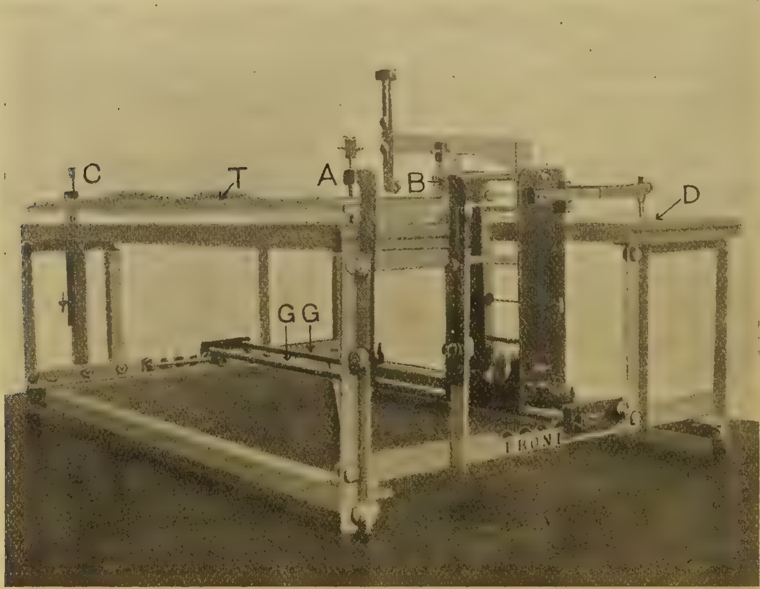

Fig. 4

is pushed along the guide rods by force applied to the handle *U*. The pencil then draws a straight datum line. The roller is then lowered into contact with the timber surface at a point of the path nearest to a clamping point and this point is marked *Z*. This point defines the position of the plane of reference, and the datum line already drawn lies in it. The lock is then released by turning the head *L* and the stock is drawn or pushed along the guide bars. The roller now follows the unevenness of the surface along the path which it is compelled to follow and the pencil *P* draws automatically the curve giving the shape of

this path twice full size. The curve is the profile of a section taken through the roller path at right angles to the plane of reference.

The process of drawing a family of curves is similar. The datum lines are first drawn one for each position of the guide frame in its

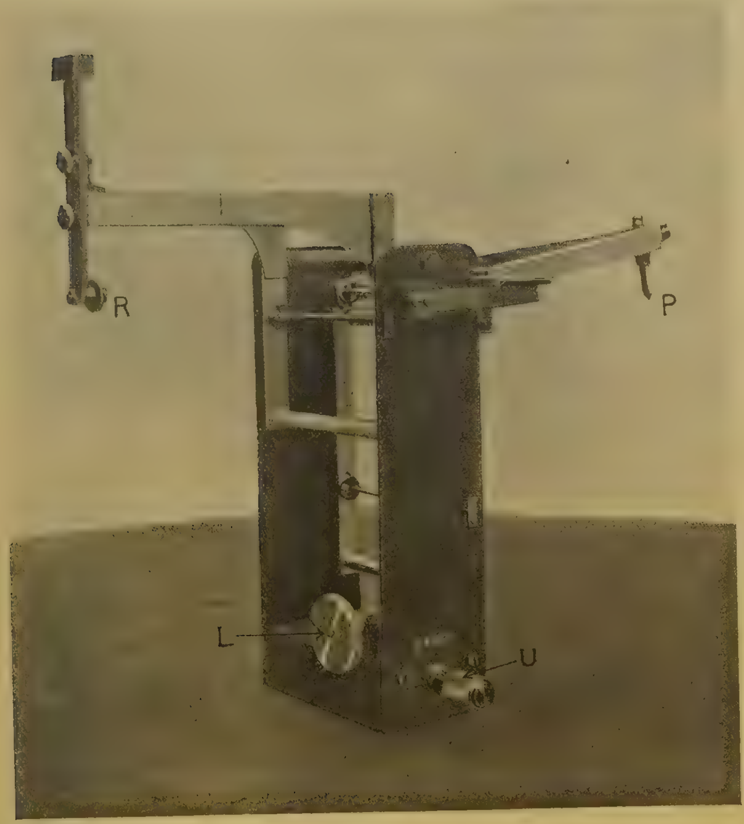

Fig. 5.

notches. Then the point Z is selected. Guide frame and stock are adjusted to bring the roller over the selected point and then the roller is lowered into contact with the surface and the roller post is securely

clamped. The profile curve corresponding to each pair of notches provided is then drawn.

The family of curves, Fig. 1, were drawn in this way.

4. Interpretation of the Profile Curves on the Record.

The datum lines lie in one plane, the plane of reference. The distance from any point on any one of the profile curves to its datum line is equal to twice the distance of the corresponding point in the timber surface to the reference plane defined by the point Z.

For example the point Y_1 on the Record No. 1 (drawn again in Fig. 6) is $\frac{1}{4}''$ above the reference plane containing the point Z on the surface of the sample. Similarly the point Y_2 is $0{\cdot}2''$ below this reference plane.

All the points on the timber surface corresponding with points of intersection of the profile curves with their respective datum lines lie in the reference plane containing Z.

For example the points on the surface corresponding to points $Zzzzz$ and $yyyyy$ in the record all lie in the plane of reference. The lines joining these points are contour lines in the reference plane.

Points on the profile curves at equal distance from their respective datum lines can be located. Curves through these points are contour curves for the particular distance located.

The family of profile curves drawn by the machine can therefore be used to find the contour lines of the surface explored. And these contour lines can be drawn on the record.

A family of profile curves of sections at right angles to those drawn automatically by the machine can be deduced. Suppose for example that the profile is required across the section SS on the record shown in Fig. 6. At each of the intersections of SS with the five datum lines of the record, set up (or down) the intercepts on SS, cut off by the respective datum lines and the corresponding profile curves. $P_1P_2P_3P_4P_5$ are points obtained in this way and the curve through them is the profile curve across the section SS.

Profile curves for a series of transverse sections at any assigned interval apart can be deduced from the family of profile curves drawn by the machine. Such a family is shown in Fig. 7 for transverse sections taken about $3''$ apart on record No. 2, a record taken from an artificially prepared surface of a sample of pine.

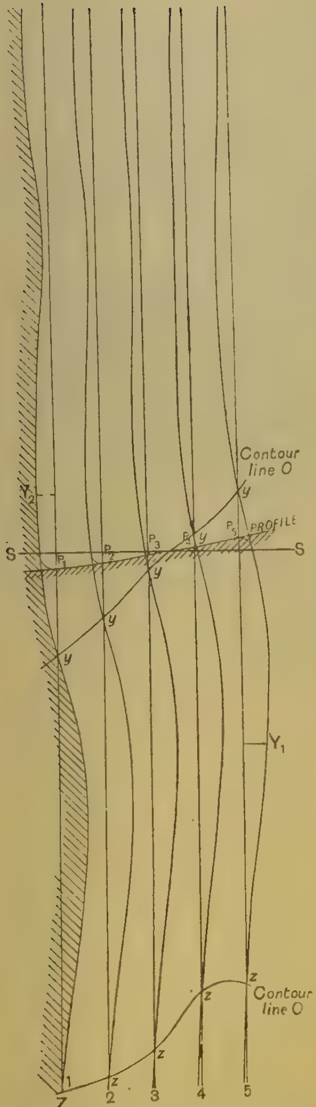

Fig. 6. PROFILE CURVES. Redrawn from Fig. 1.

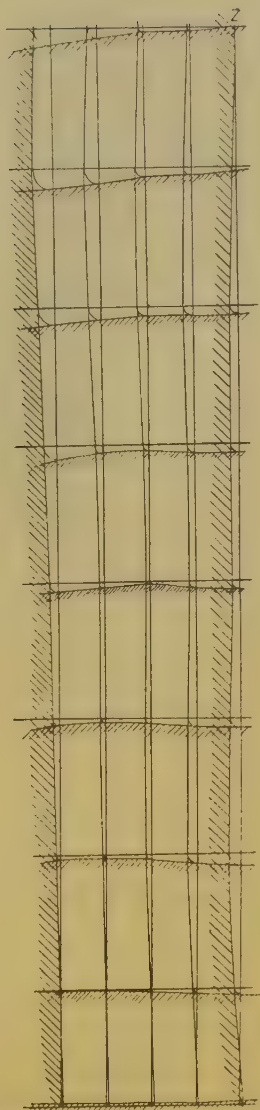

Fig. 7. Showing a family of profile curves taken from an artificially prepared surface of a pine sample together with a family of transverse profile curves deduced from them.

Each of these diagrams is a little larger than ¼ full size. In the original records the datum lines are 1 inch apart.

5. Use of the Record to plot a Contour Line on the Timber Surface.

The point on the timber surface corresponding to any point on the record can be identified by placing guide frame and stock so that the pencil is brought over the point on the record. The roller will then mark the corresponding point on the timber surface.

The series of points lying on a contour line on the record can thus be identified on the timber surface and an actual contour line can then be drawn on the timber surface itself. The meaning of such a line is that all points on it are equally distant from the reference plane containing the point Z and parallel to the points A, B and C which have been definitely imprinted on the timber surface by the three studs against which the timber sample was clamped.

THE ACTION OF ENCHYTRAEID WORMS

By the Rev. HILDERIC FRIEND, F.R.M.S.

The following paper is based on the Report which was presented to the Board of Agriculture as the result of experiments carried out in 1914–15 under the direction of Professor Gamble, F.R.S., at the Birmingham University.

The main objects were twofold:

1. To determine the question of the injurious action of Enchytraeid worms on living plants.

A long series of experiments was conducted at the Edgbaston Botanic Gardens with Asters, Antirrhinums and other plants, with a view to ascertaining what effect, if any, was produced upon the living plants by the presence of these worms, which had frequently been charged with causing decay and death. Control plants were used, and infections were made with various species of worms under a great variety of conditions. The results showed conclusively that so long as the plants are healthy and vigorous Enchytraeids do not attack them. On the other hand, when living plants begin to decline from any cause it is the usual thing for white worms to take up the work of destruction and play the part of scavengers.

While the experiments were in progress visits were paid to Droitwich, Kenilworth, Shrewsbury, Edgbaston and other places in which gardens were reported to be suffering from injurious Enchytraeid attacks. In no instance was the evidence sufficient to justify the opinion that white worms were the original aggressors, though in several instances they were busily engaged in clearing away the decaying plants. The initial injury was due to a variety of causes, such as fungi, bacteria, Julus and other pests.

2. To determine the rôle of the red-blooded Enchytraeids.

During the year advantage was taken of many opportunities to study both in the field and in the experiment house, the rôle of that group of minute worms belonging to the Enchytraeids which are characterized by red blood. They are found in moist places among vegetable debris, in sewage works, ponds, ditches, farmyards and especially by the seaside, and are found to be invariably engaged as beneficent scavengers. Though not infrequently met with in tap water their

presence is never occasion for alarm, and even if they were inadvertently swallowed no injurious effects need be feared. A report will appear in *Science Progress* for July.

The following details of observations and experiments have been selected from a large number which have been carried out, as they tend to the elucidation of the foregoing report.

1. *Antirrhinum Cultures.* (1) The object was to determine whether or not Enchytraeid worms caused failure and death.

In December 1914, twelve plants were purchased from Messrs Simpson, Florists, such as they were rearing for market. Six plants were retained for control. The other six were inoculated with Enchytraeids which had been found associated with sickly plants and were suspected of being inimical. The plants were kept in an Experiment House at Edgbaston Botanic Gardens, and regularly watched and examined. For a time the inoculated plants looked paler than the controls, but eventually they showed themselves to be stronger. All plants survived. In April 1915, the six plants were again inoculated. Blossoms perfected at the same time on both sets of plants. On May 1, the pots containing inoculated plants were examined, and found to contain many worms, but the roots were all healthy. Plants were then transferred to the Garden, and all treated alike with Enchytraeids, but not one succumbed.

2. *Antirrhinum Cultures.* (2) It was reported that Antirrhinums were suffering from root worms at Droitwich. A visit was paid to the Experimental Gardens, the plants inspected, and specimens brought away with soil. The soil contained many Enchytraeids, but was also full of Julus larvae and other suspects. These were removed, and the plants repotted with all the Enchytraeids as found. One plant died, the evidence showing that it was too weak to survive removal. The others rallied and became very vigorous in spite of the worms.

Slips taken from both these sets of Antirrhinum took root readily and made healthy plants.

3. *Antirrhinum pests.* While these cultures and experiments were in progress many plants which were diseased at Edgbaston, Kenilworth and elsewhere were examined. In the case of seedlings, forced in frames and greenhouses, fungoid growths were the chief cause of failure. Out-of-door plants suffered from various causes, but in no instance could evidence be found for convicting Enchytraeids.

4. *Aster Cultures.* December 2, 1914, Messrs Sutton and Sons, Reading, kindly supplied three packets of seed for experiment. These were *A. sinensis* (type) with the varieties *Victoria* and *Ostrich Plume.* The Head Gardener at Edgbaston had ceased to grow Asters as they had of recent years proved a complete failure.

The foreman sowed seeds of each kind (which were marked 1, 2 and 3) in the soil used in the gardens used for bringing on seedlings, and these were allowed to grow till they were ready for repotting. While a number of plants were reserved in the original large pots for control, others were planted in (1) loam, (2) sterilized leaf mould, and (3) Enchytraeus infected soil and manure. They grew side by side and flourished.

Next, some of the repotted plants were inoculated with Enchytraeids while the rest were retained as controls, but not a single plant fell a victim to the treatment.

A second set of experiments yielded the same results. Seeds of the same samples were sown in pots containing (1) loam, (2) sterilized leaf mould, (3) Enchytraeus infected soil and (4) sand. These in due course were infected with Enchytraeids, including species found in the rubbish heaps in the Botanical Gardens; and again, all survived.

Some of the plants were transferred to the open border, and others planted in soil containing Enchytraeids, but they made the most perfect growth.

5. *Miscellaneous investigations.* During the year, every opportunity which presented itself for investigating plant diseases was utilized. Turnips near Coventry, Lilies at Shrewsbury, Peas at Erdington, bowling green Grass on the Solway, and fairy rings at Cheltenham were carefully examined, and all the evidence for and against the Enchytraeids carefully weighed. In no single instance could it be shown that white worms were the aggressors, but there were frequent evidences that Enchytraeids came in as secondary agents when plants were already weakened, and so played the part of scavengers.

Conclusion. Enchytraeid worms are abundant in leaf mould, and are often found associated with decaying field and garden crops on which account they have been suspected of causing their decay and death. The evidence shows that they are a beneficent group of animals of great economic value to the forester, gardener and farmer. They break up decaying matter and prepare it for further service but it remains to be shown that in any case they are the direct cause of the diseases of plants.

THE FOOD OF SLUGS AND THE DEVELOPMENT OF ANOPLOCEPHALIDAE

By Professor A. RAILLIET,
Ecole vétérinaire d'Alfort,
Foreign Member of the Association of Economic Biologists.

I have just read, a little tardily, but with much interest, the note of Miss Marie V. Lebour, "Some feeding habits of slugs," published in *The Annals of Applied Biology*, Vol. I, Nos. 3–4, January 1915, p. 393.

Miss Lebour has discovered that the slugs, *Agriolimax agrestis* and *Arion circumscriptus*, ingest very greedily the proglottids of two Anoplocephalidae,—*Moniezia expansa* of sheep and *Cittotaenia pectinata* of rabbits; she has ascertained that the eggs of these Cestodes pass through the intestine of the Molluscs without undergoing alteration, the six-hooked embryos remaining alive; but she has not discovered any trace of the larval Cestodes in the body of the slug.

It may not perhaps be without interest to record, in this connection, the results of an experiment, very imperfect, but nevertheless important, which I had occasion to make twenty years ago and about which I have just found certain short notes.

On November 4, 1892, I collected from the faeces of a carrier pigeon coming from Neufchâtel-en-Bray (Normandy) some proglottids of *Bertiella delafondi*; these proglottids, macerated in a little water, were placed on a cabbage leaf with four grey slugs (*Agriolimax agrestis*). The next morning, I noticed that almost the whole of the contaminated leaf had been eaten.

On the 14th of November, I dissected one of these slugs, but could only find some Nematodes and Trematodes.

On the 8th and 30th of November, I repeated this operation with chicory leaves and a second lot of six grey slugs. On the 14th of December, I fed two pigeons on these slugs, each receiving three. Towards the middle of January, one of these pigeons began to evacuate proglottides of *Bertiella delafondi*.

As can be seen, this experiment has been left unfinished, since I have not observed in slugs the larval form of the parasite, and unfortunately I have not had an opportunity of repeating the experiment.